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Flavour physics at the Intensity Frontier

Peter Križan

University of Ljubljana and J. Stefan Institute

University of Ljubljana

"Jožef Stefan" Institute

Contents

- Highlights from Belle (+ a little bit of history)
- Physics case for a super B factory
- Accellerator and detector upgrade → SuperKEKB + Belle-II
- Status and outlook

A little bit of history...

CP violation: difference in the properties of particles and their anti-particles – first observed in 1964 in the decays of neutral kaons.

M. Kobayashi and T. Maskawa (1973): CP violation in the Standard model – related to the weak interaction quark transition matrix

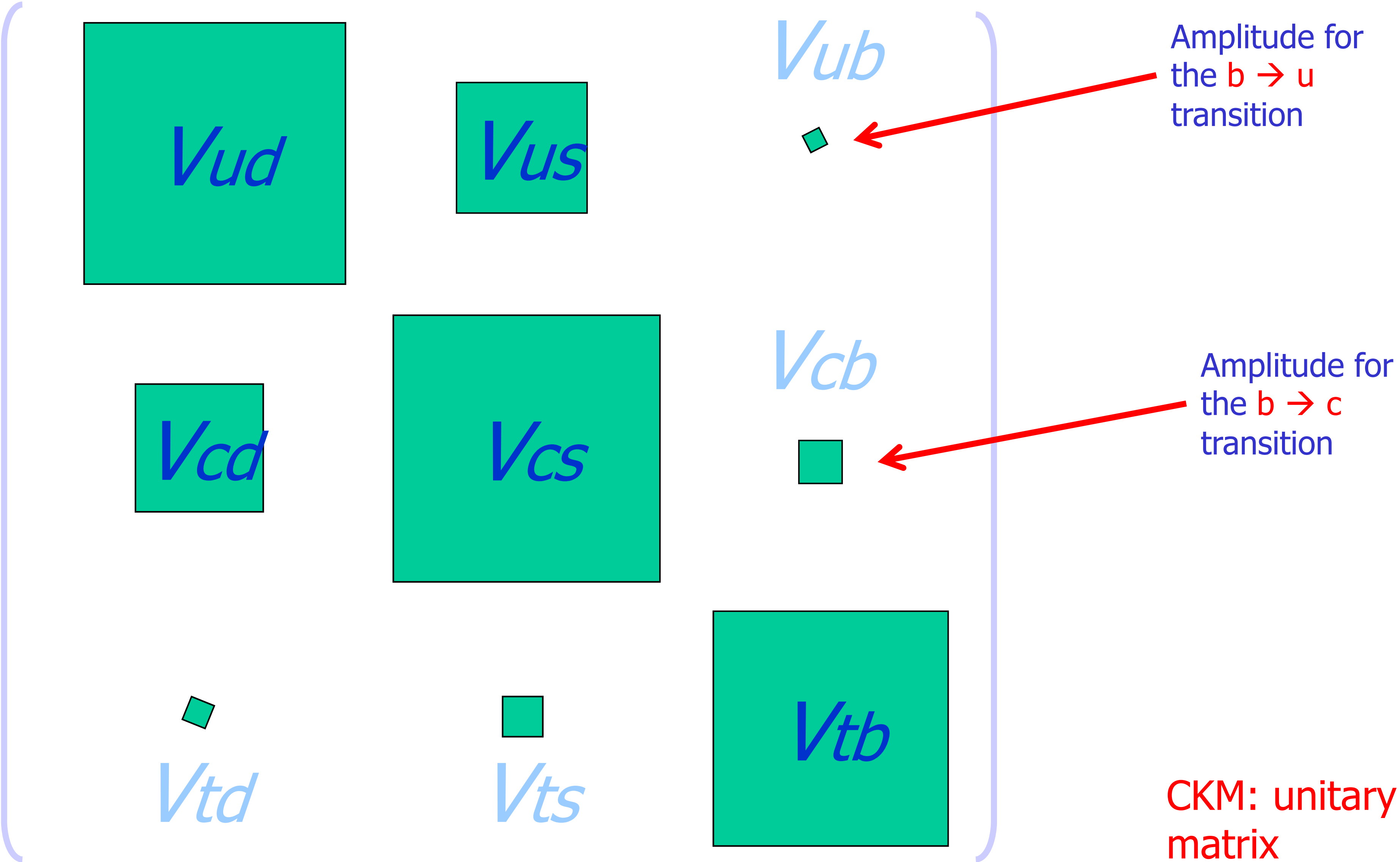
Their theory was formulated at a time when three quarks were known – and they requested the existence of three more!

The last missing quark was found in 1994.

... and in 2001 two experiments – Belle and BaBar at two powerfull accelerators (B factories) - have further investigated CP violation and have indeed proven that it is tightly connected to the quark transition matrix

CKM - Cabibbo-Kobayashi-Maskawa (quark transition) matrix:

almost real and diagonal, but not completely!



CKM: unitary matrix

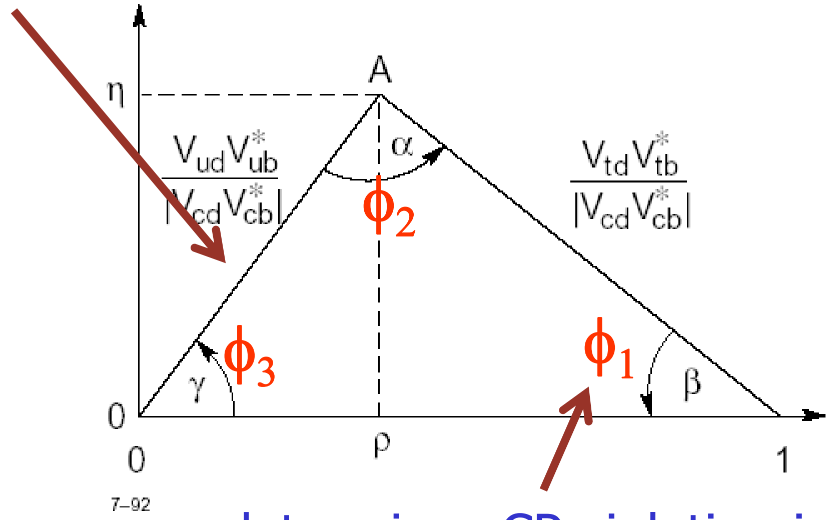
CKM matrix: determines charged weak interaction of quarks

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

A, ρ and η: all of order one

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

determines probability of b→u transitions



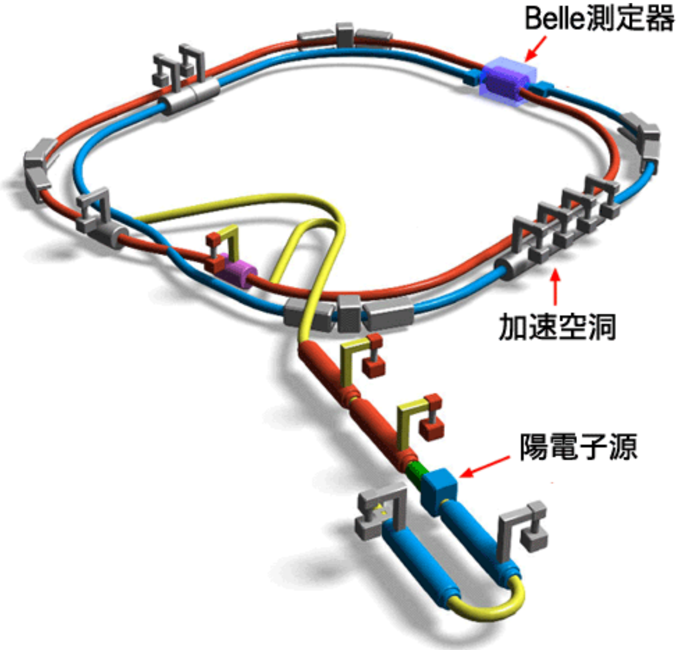
determines CP violation in $B \to J/\psi\, K_S$ decays

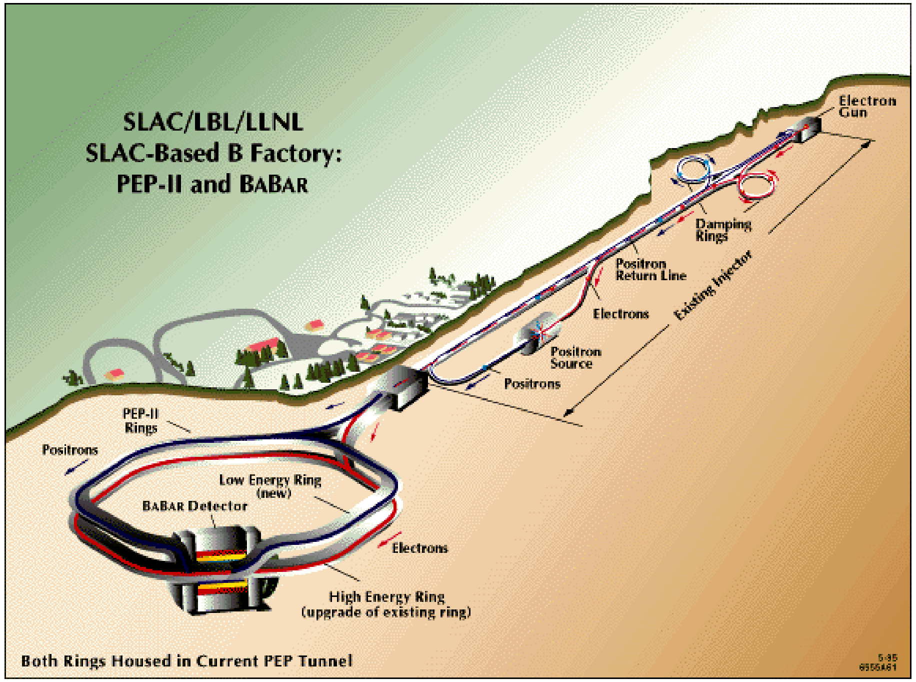
Unitarity condition:

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

Goal: measure sides and angles in several different ways, check consistency →

Asymmetric B factories





$\sqrt{s}$=10.58 GeV

e^+ → $\Upsilon(4s)$ ← e^-

$\Upsilon(4s)$ → B, $\bar{B}$

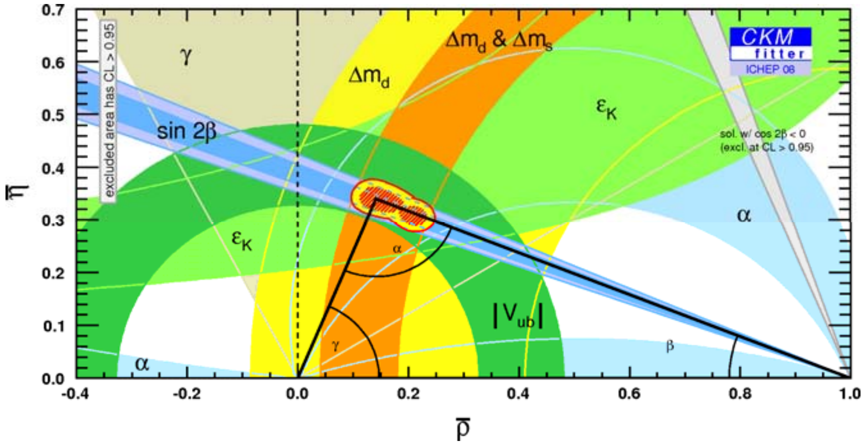
$\Delta z \sim c\beta\gamma\tau_B$

$\sim 200\mu m$

BaBar	$p(e^-)$=9 GeV	$p(e^+)$=3.1 GeV	$\beta\gamma$=0.56
Belle	$p(e^-)$=8 GeV	$p(e^+)$=3.5 GeV	$\beta\gamma$=0.42

KM's bold idea verified by experiment

Relations between parameters as expected in the Standard model →

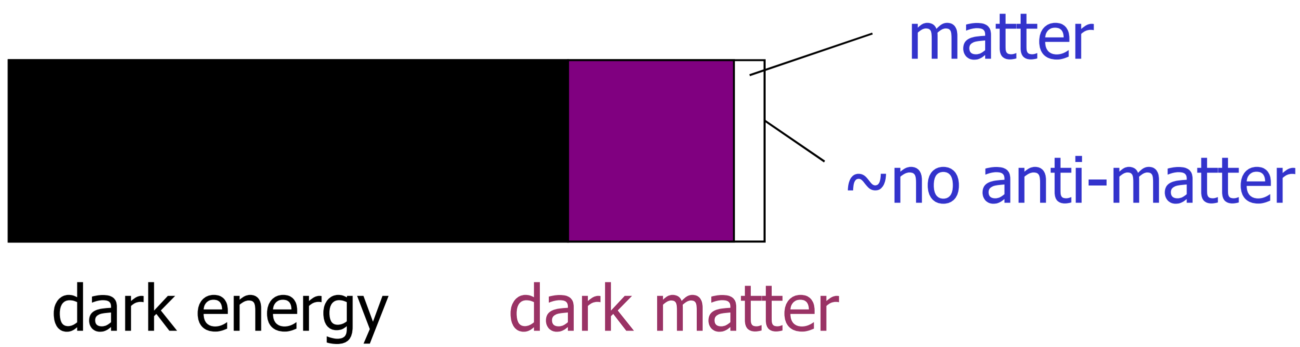


Nobel prize 2008!

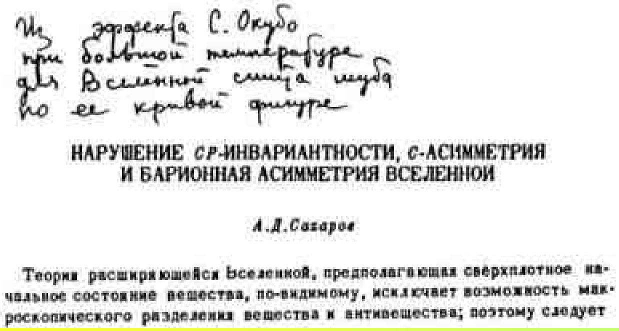
→ With essential experimental confirmations by Belle and BaBar! (explicitly noted in the Nobel Prize citation)

The KM scheme is now part of the Standard Model of Particle Physics

- However, the CP violation of the KM mechanism is too small to account for the asymmetry between matter and anti-matter in the Universe (falls short by 10 orders of magnitude !)
- SM does not contain the fourth fundamental interaction, gravitation
- Most of the Universe is made of stuff we do not understand...



Are we done ? (Didn't the B factories accomplish their mission, recognized by the 2008 Nobel Prize in Physics ?)



Из эффекта С. Окубо
при большой температуре
для Вселенной сшита шуба
по ее кривой фигуре

НАРУШЕНИЕ *CP*-ИНВАРИАНТНОСТИ, *C*-АСИММЕТРИЯ И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д.Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует

Matter - anti-matter asymmetry of the Universe: KM (Kobayashi-Maskawa) mechanism still short by 10 orders of magnitude !!!

Two complementary approaches to study shortcomings of the Standard Model and to search for the so far unobserved processes and particles (so called New Physics, NP). These are the **energy frontier** and the **intensity frontier** .

Energy frontier : direct search for production of unknown particles at the highest achievable energies.

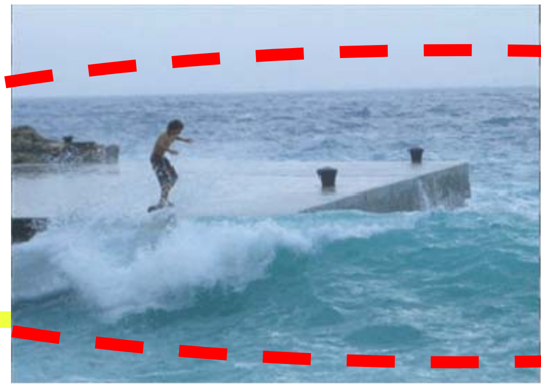
Intensity frontier : search for rare processes, deviations between theory predictions and experiments with the ultimate precision.

→for this kind of studies, one has to investigate a very large number of reactions (″events″) → need accelerators with ultimate **intensity** (″luminosity″)

Comparison of energy /intensity frontiers

To observe a large ship far away one can either use **strong binoculars** or observe **carefully the direction and the speed of waves** produced by the vessel.

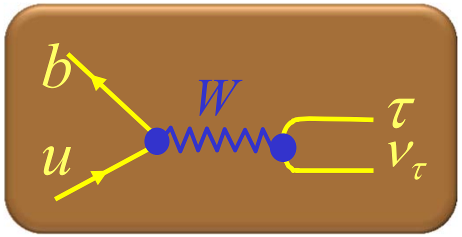
Energy frontier (LHC)



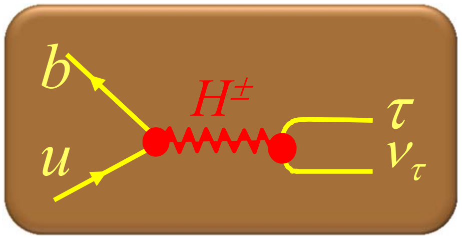
Luminosity frontier (Belle and Belle II)

An example: Hunting the charged Higgs in the decay $B^- \rightarrow \tau^- \nu_\tau$

In addition to the Standard Model Higgs to be discovered at the LHC, in New Physics (e.g., in supersymmetric theories) there could be another ´God particle´– a charged Higgs.



The rare decay $B^- \rightarrow \tau^- \nu_\tau$ is in SM mediated by the W boson

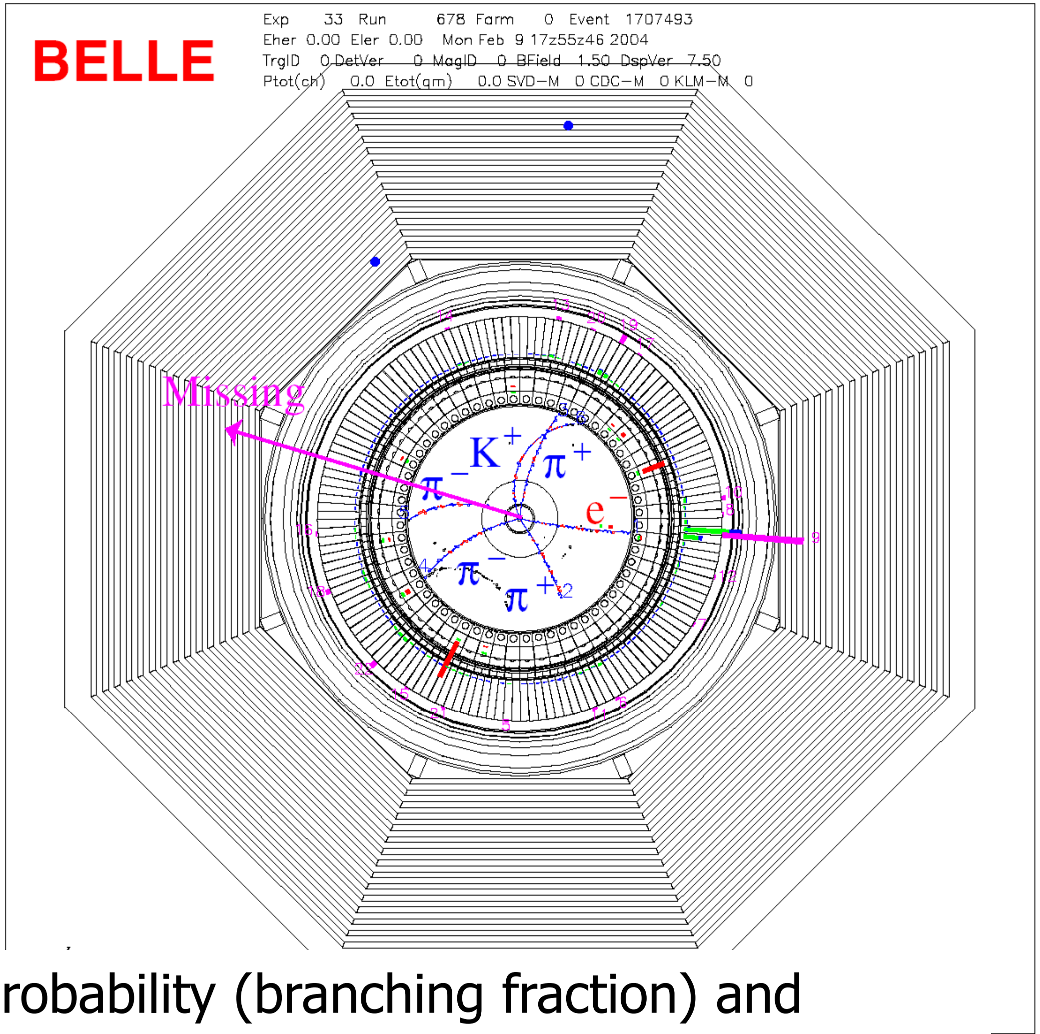


In some supersymmetric extensions it can also proceed via a charged Higgs

The charged Higgs would influence the decay of a B meson to a tau lepton and its neutrino, and modify the probability for this decay.

Missing Energy Decays: $B^- \to \tau^- \nu_\tau$

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



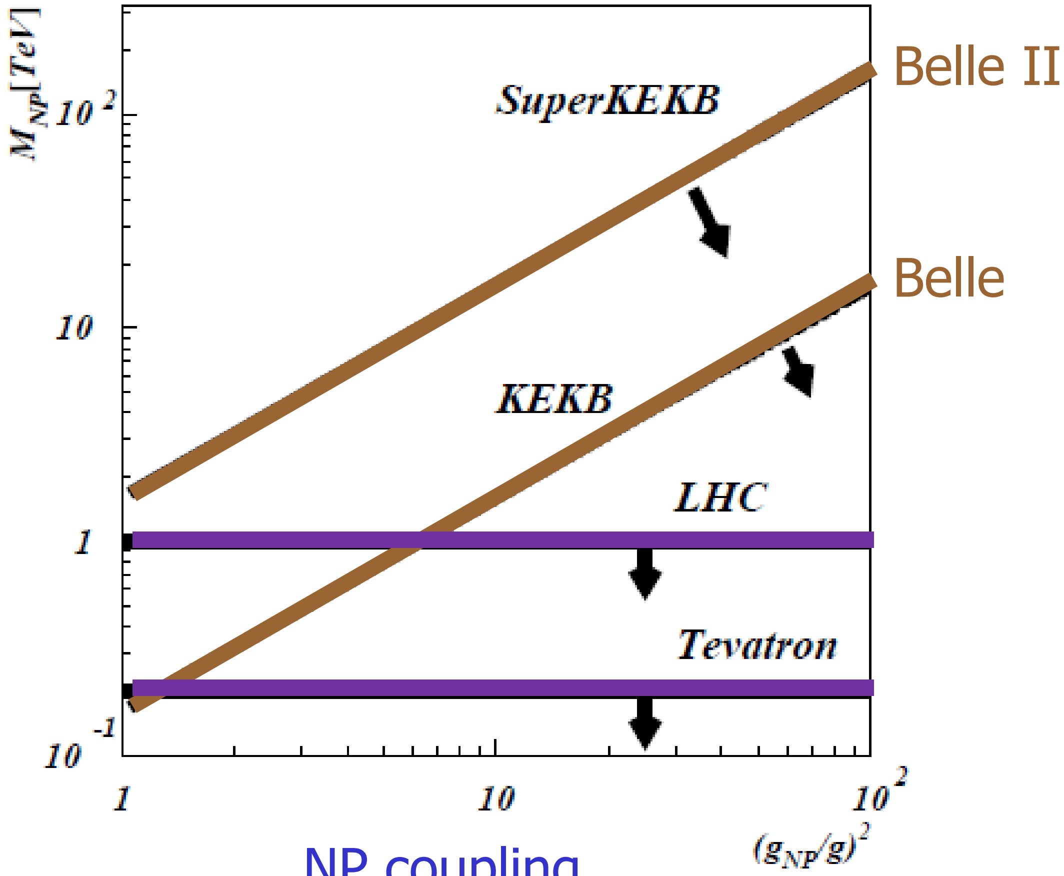
By measured the decay probability (branching fraction) and comparing it to the SM expectation:

→ Properties of the charged Higgs (e.g. its mass)

New Physics reach

energy frontier vs. **intensity frontier**

NP mass scale
(TeV)

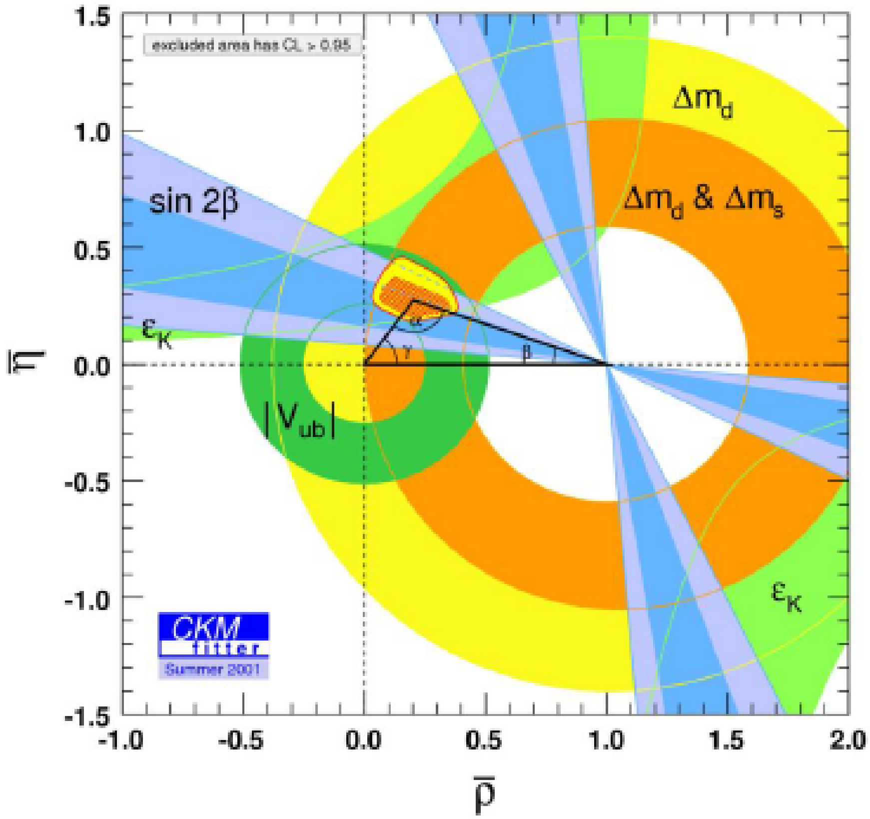


NP coupling

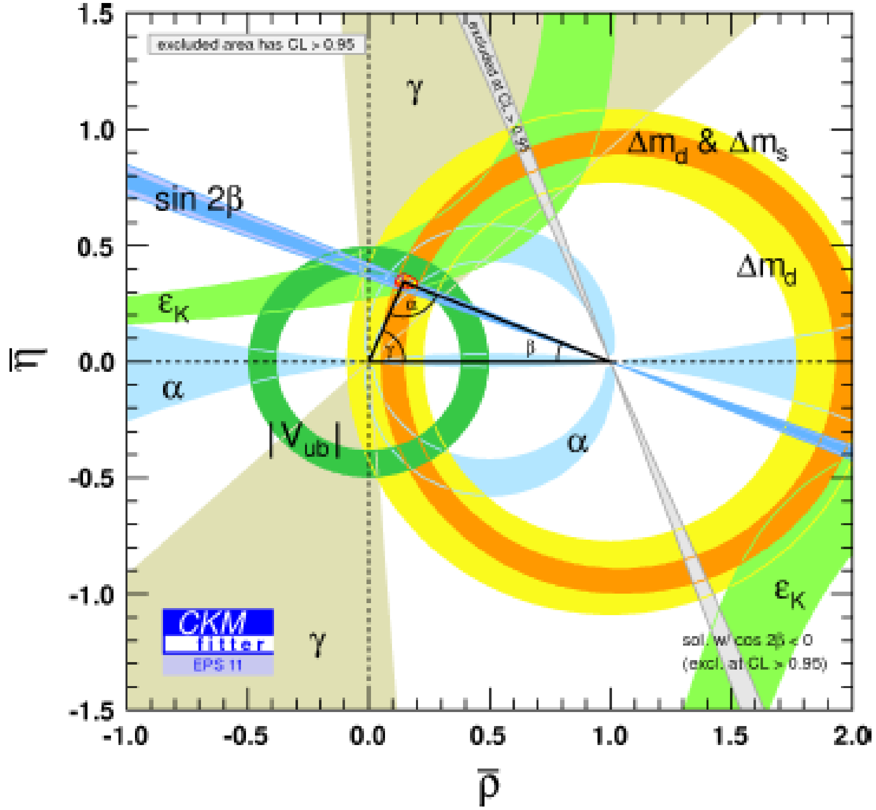
Unitarity triangle – 2011 vs 2001

CP violation in the B system: from the discovery (2001) to a precision measurement (2011).

EPS 2001



EPS 2011



Unitarity triangle – new/final measurements

Constraints from measurements of angles and sides of the unitarity triangle → Remarkable agreement, but still 10-20% NP allowed
→ search for New Physics!

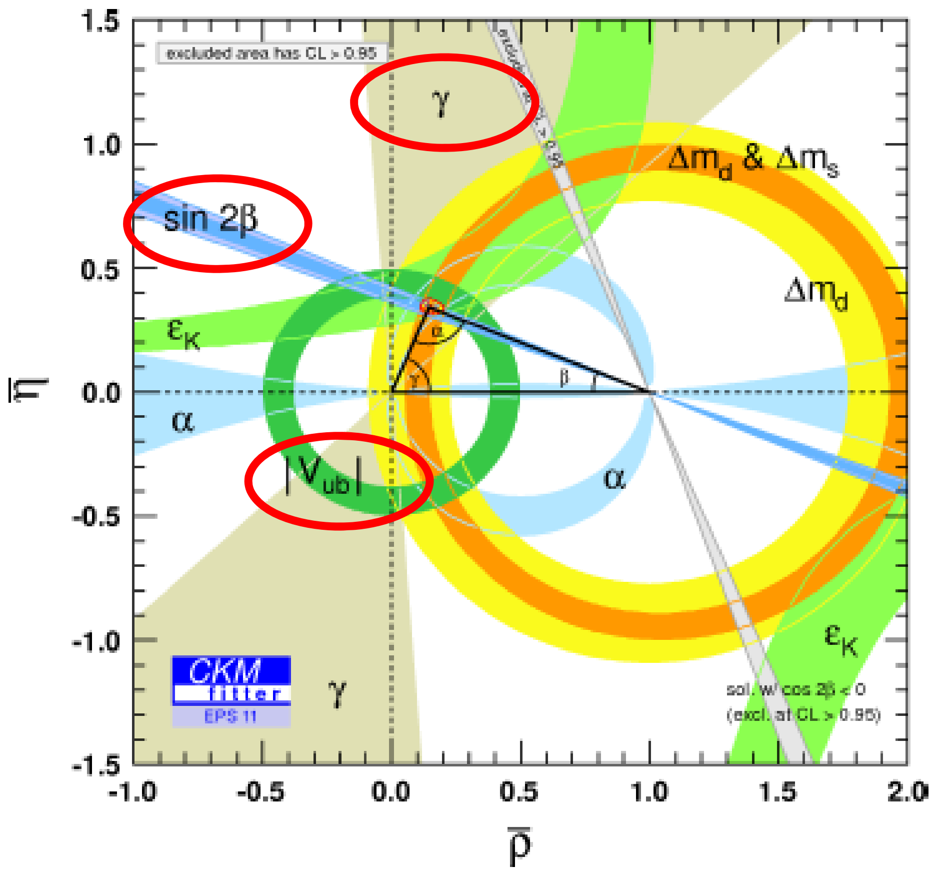
This summer:

Unitarity triangle:

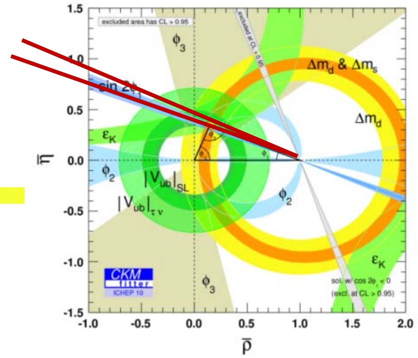
→ $\sin2\phi_1$ (= $\sin2\beta$) : final measurement from Belle

→ ϕ_3 (= γ) new model-independent method

→ $|V_{ub}|$ from exclusive and inclusive semileptonic decays

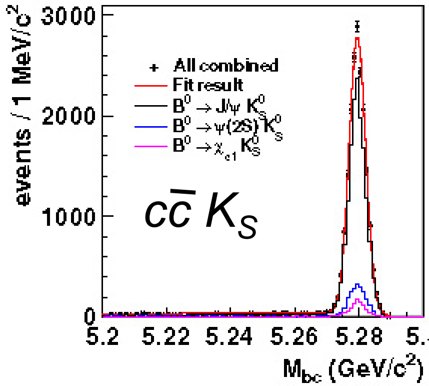


Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)



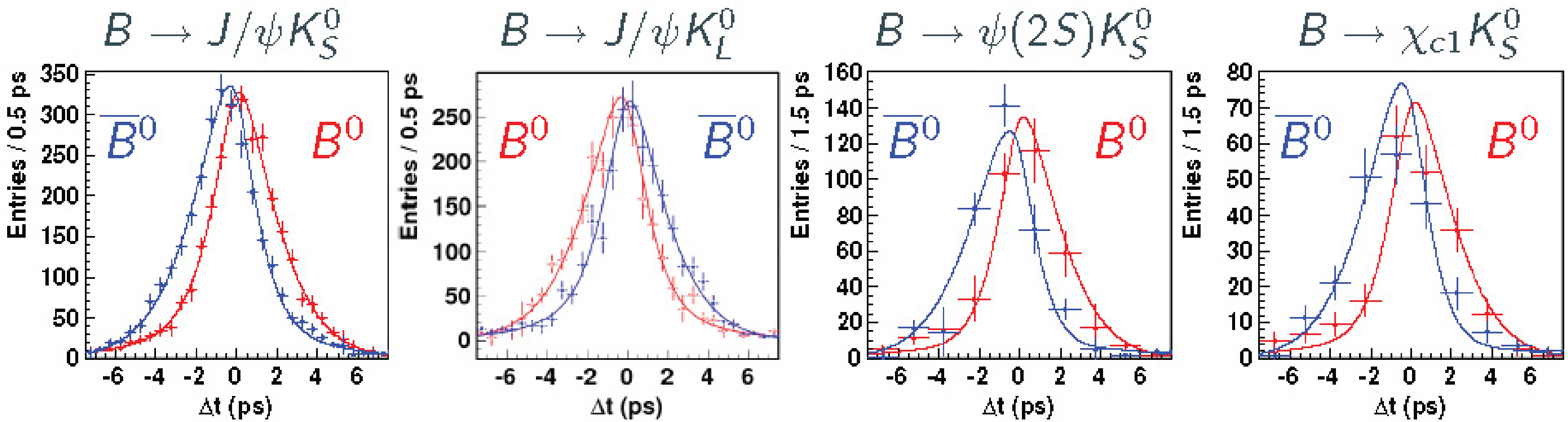
Belle, preliminary, 710 fb^{-1}

ϕ_1 from CP violation measurements in $B^0 \rightarrow c\bar{c}\,K^0$



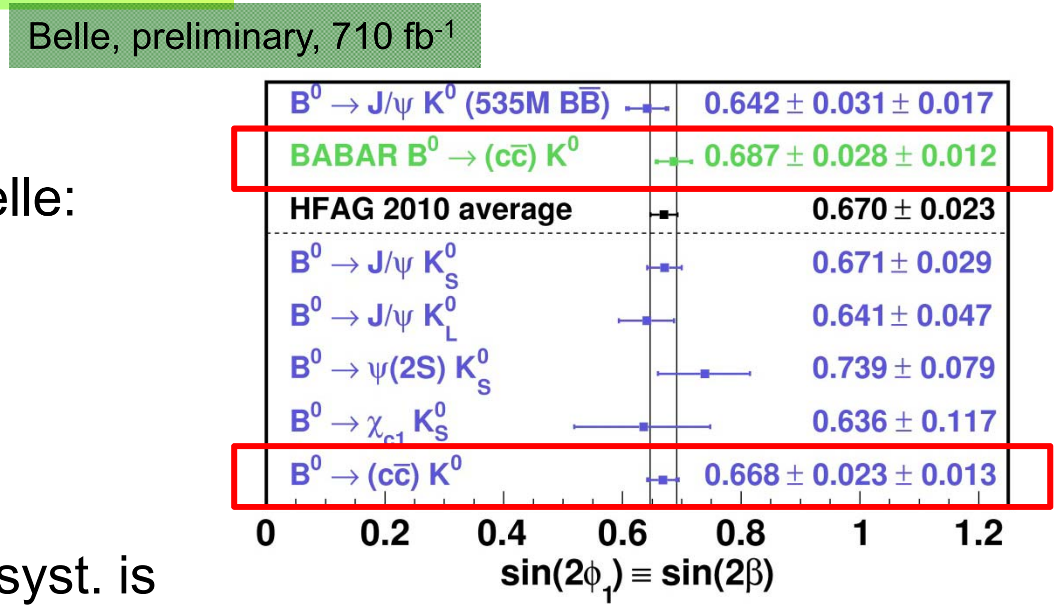
Improved tracking, more data
(50% more statistics than last result with 480 fb^{-1});
$c\bar{c}$ = J/ψ, $\psi(2S)$, χ_{c1} → 25k events

detector effects: wrong tagging, finite Δt resolution, determined using control data samples



Final measurement of $\sin 2\phi_1$ (=$\sin 2\beta$)

ϕ_1 from $B^0 \rightarrow c\bar{c}\, K^0$



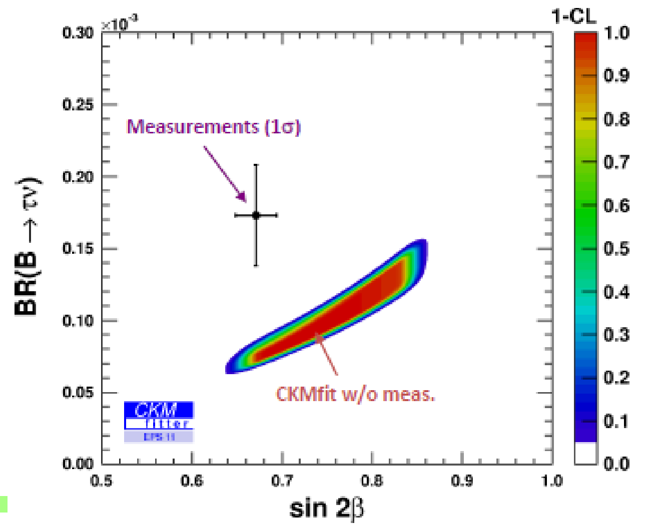
Final result (preliminary) from Belle:

S= 0.668 ± 0.023 ± 0.013
A= 0.007 ± 0.016 ± 0.013

(SM: $S=\sin 2\phi_1$ (=$\sin 2\beta$), A=0)

Still statistics limited, part of the syst. is statistics dominated!

Tension between $\mathcal{B}(B \rightarrow \tau\nu)$ and $\sin 2\phi_1$ (~2.5 σ) remains



CP violation in B → D^+D^- and $D^{*+}D^{*-}$

SM: b→ccd, S=sin2ϕ_1 (=sin2β), A=0

B → D^+D^-

Belle preliminary

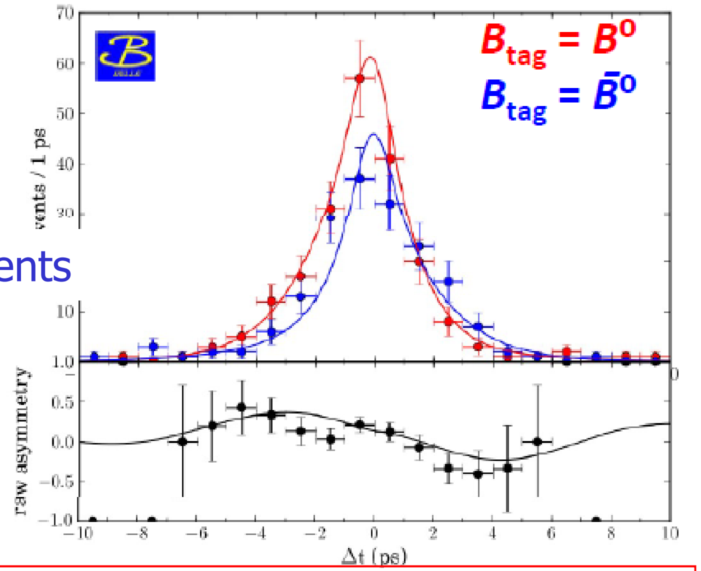
$$S = -1.06 \pm 0.18 \pm 0.07$$

$$A = +0.43 \pm 0.16 \pm 0.04$$

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

$B^0 \to (K^-\pi^+\pi^+)(K^+\pi^-\pi^-)$, $(K^-\pi^+\pi^+)(K_S\pi^0)$+c.c.

320 events



Previous measurement (535x10^6 $B\bar{B}$ pairs):

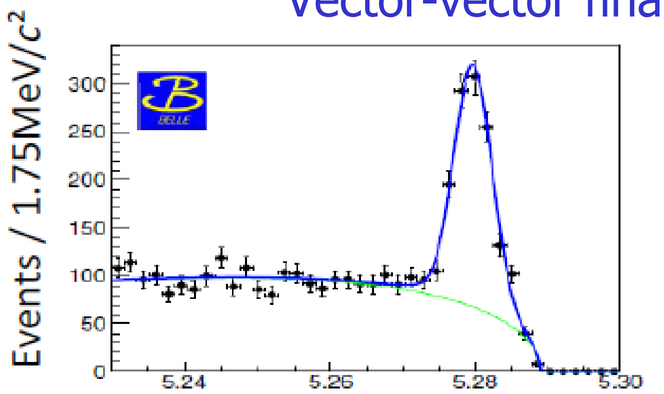
$$S = -1.13 \pm 0.37 \pm 0.09,$$

$$A = +0.91 \pm 0.23 \pm 0.06$$

→ Large CP violation effects in many places in B decays!

B→$D^{*+}D^{*-}$

Vector-vector final state, need angular analysis for CPV measurement



N_{sig}=1225±59

1225 events, >2x increase in yield vs the 2009 paper

$$S = -0.79 \pm 0.13 \pm 0.03$$

$$A = +0.15 \pm 0.08 \pm 0.02$$

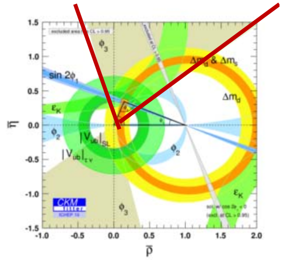
$$R_0 = 0.63 \pm 0.03 \pm 0.01$$

$$R_\perp = 0.14 \pm 0.02 \pm 0.01$$

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

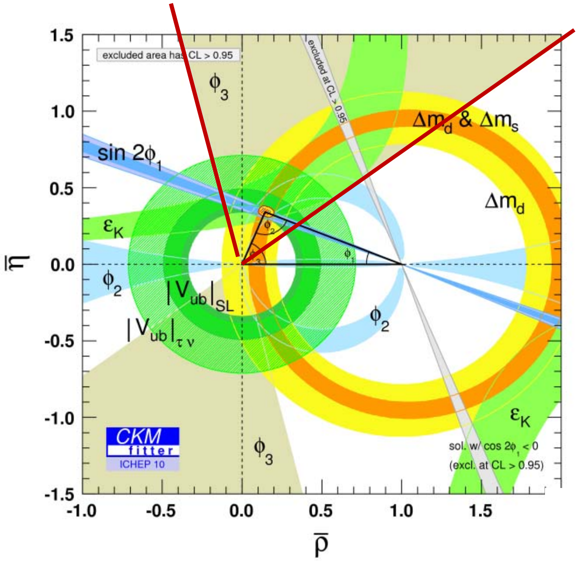
Belle preliminary

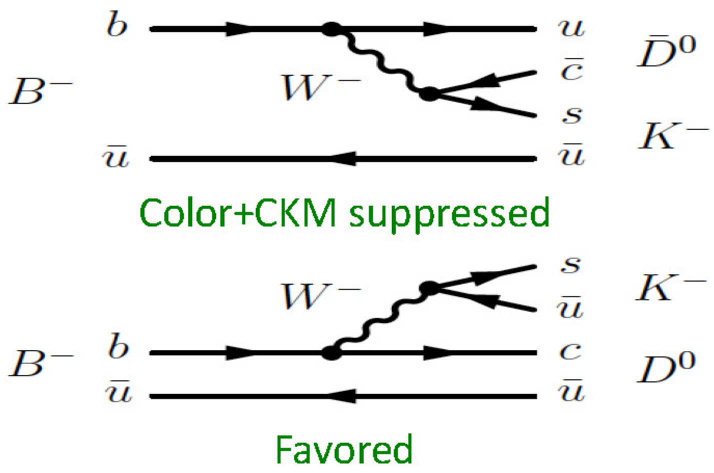
ϕ_3 (=γ) with Dalitz analysis



Dalitz method:

The best way to measure ϕ_3





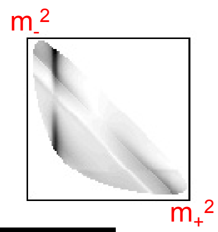
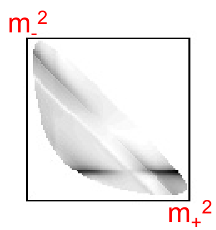
Giri et al., PRD68, 054018 (2003)
Bondar et al.

$\overset{(-)}{D^0} \to K_S\pi^+\pi^-$

$m_+ = m(K_S\pi^+)$
$m_- = m(K_S\pi^-)$

3-body $D^0 \to K_S\pi^+\pi^-$ Dalitz amplitude

$$|M_\pm(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta_B \pm i\phi_3} f_D(m_-^2, m_+^2)|^2$$

$$= \Big|$$  $$+ re^{i\delta_B \pm i\phi_3}$$  $$\Big|^2$$

model dependent description of f_D using continuum D* data $\Rightarrow$ systematic uncertainty

ϕ_3=(78 ± 12 ± 4 ± 9)°

Belle, PRD81, 112002, (2010), 605 fb^{-1}

ϕ_3=(68 ± 14 ± 4 ± 3)°

BaBar, PRL 105, 121801, (2010)

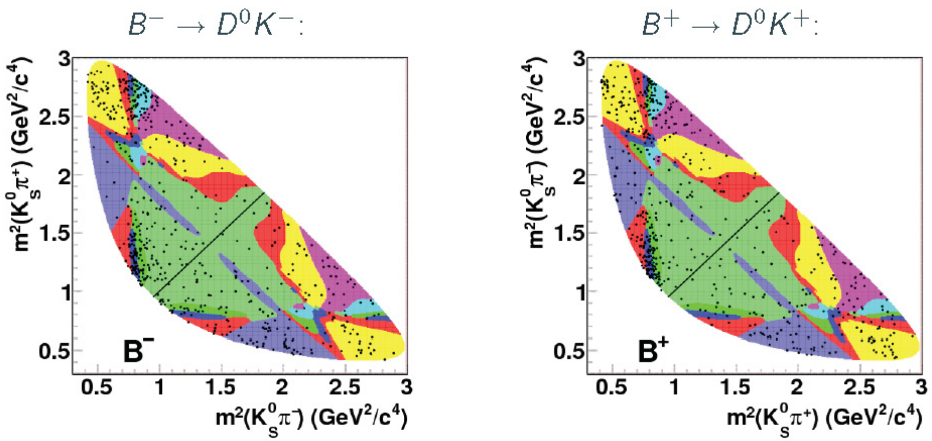
ϕ_3 (=γ) from model-independent/binned Dalitz method

Dalitz method: How to avoid the model dependence?

→ Suitably subdivide the Dalitz space into bins

$$M_i^{\pm} = h\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_{\pm} c_i + y_{\pm} s_i)\}$$

$$x_{\pm} = r_B \cos(\delta_B \pm \phi_3) \quad y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$$



M_i: # B decays in bins of D Dalitz plane, K_i: # D^0 ($\overline{D^0}$) decays in bins of D Dalitz plane ($D^* \to D\pi$), c_i, s_i: strong ph. difference between symm. Dalitz points ← Cleo, PRD82, 112006 (2010)

Use only DK

N_{sig} = 1176 ± 43

Belle, 710 fb^{-1}

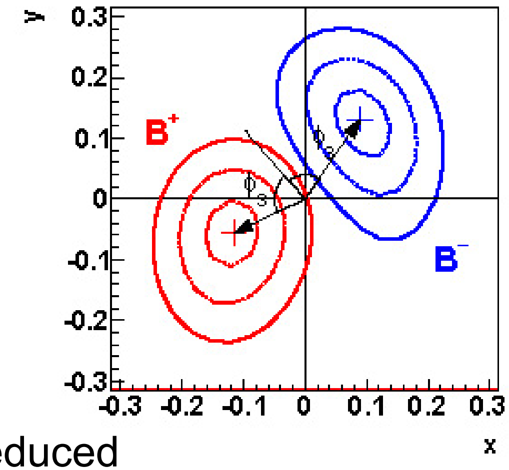
arXiv:1106.4046

4-dim fit for signal yield (ΔE, M_{bc}, $\cos\theta_{thrust}$, $\mathcal{F}$);

ϕ_3=(77 ± 15 ± 4 ± 4)^o

from c_i, s_i (statist.!)

to be reduced with BESIII data



Important method upgrade for large event samples at LHCb and super B factories

ϕ_3 with the ADS method

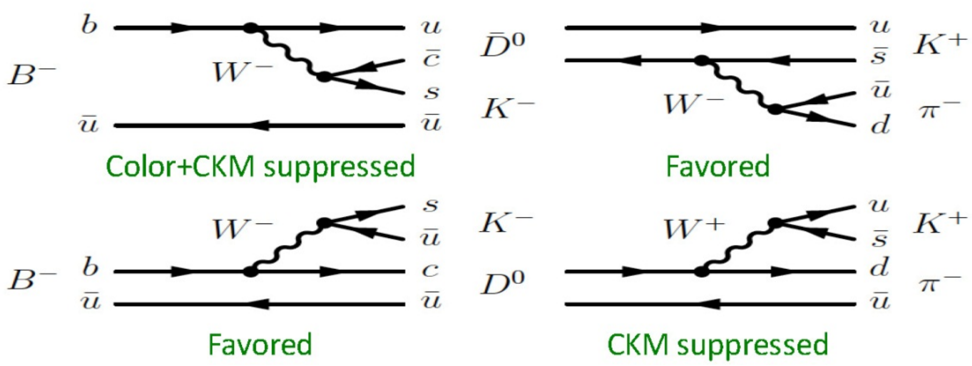
D. Atwood, I. Dunietz, A. Soni, PRL78, 3257 (1997)

$B^- \to [K^+\pi^-]_D K^-$ compared to
$B^- \to [K^-\pi^+]_D K^-$

$$\mathcal{R}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^-\pi^+]_D K^-) + \mathcal{B}([K^+\pi^-]_D K^+)}$$

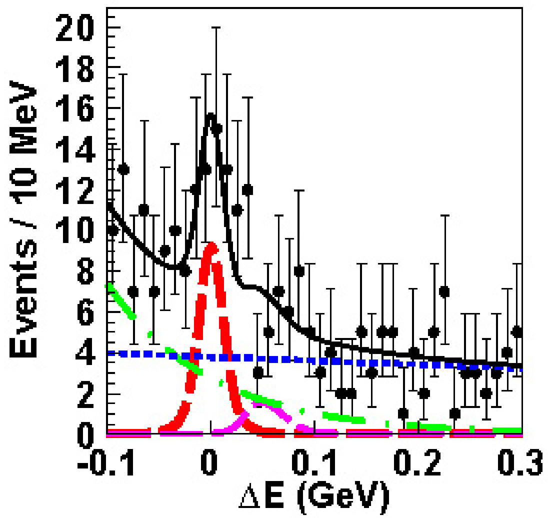
$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]_D K^-) - \mathcal{B}([K^-\pi^+]_D K^+)}{\mathcal{B}([K^+\pi^-]_D K^-) + \mathcal{B}([K^-\pi^+]_D K^+)}$$

using additional input on r_B, r_D, ϕ_3 can be extracted in a model independ. manner



$$\mathcal{R}_{DK} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\phi_3,$$
$$\mathcal{A}_{DK} = 2 r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3 / \mathcal{R}_{DK},$$

Breakthrough 2011: first evidence of the CKM supressed mode



$B^- \to [K^+\pi^-]_D K^-$
N_{sig}=56 ±15, 4.1 σ sign.,

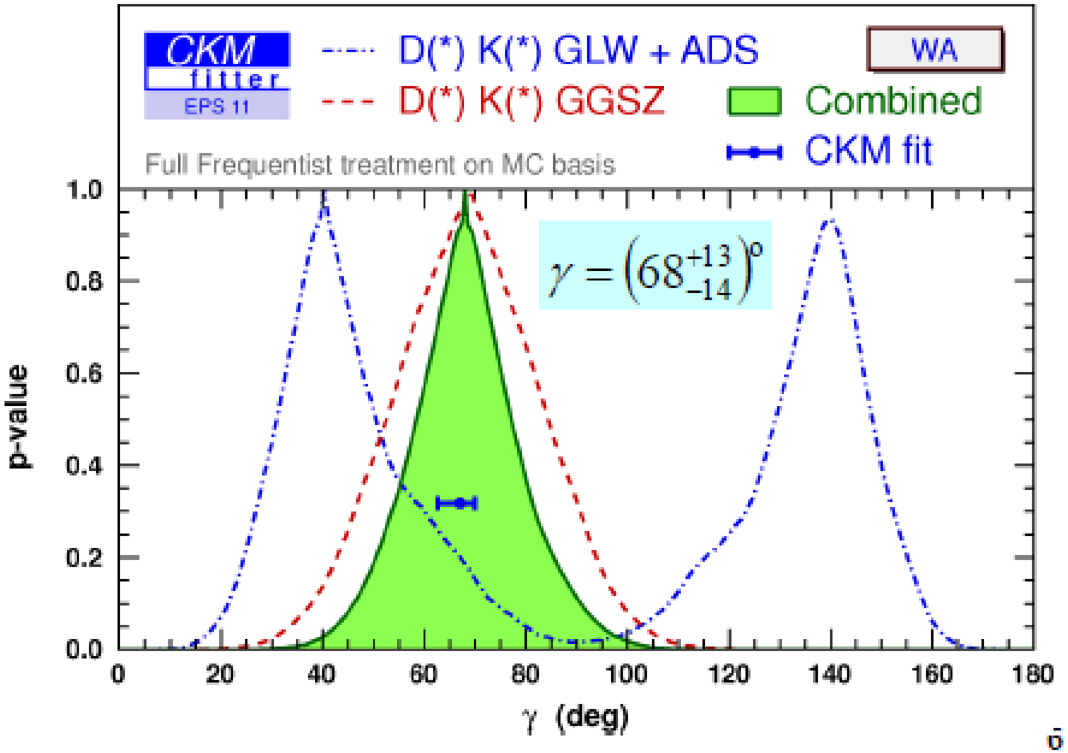
$R_{DK} = (1.63\ ^{+0.44}_{-0.41}\ ^{+0.07}_{-0.13}) \cdot 10^{-2}$
$A_{DK} = -0.39\ ^{+0.26}_{-0.28}\ ^{+0.04}_{-0.03}$

Belle, PRL 106, 231803 (2011)
arXiv:1103:5951, 710 fb^{-1}

ϕ_3 measurement

Combined ϕ_3 value:

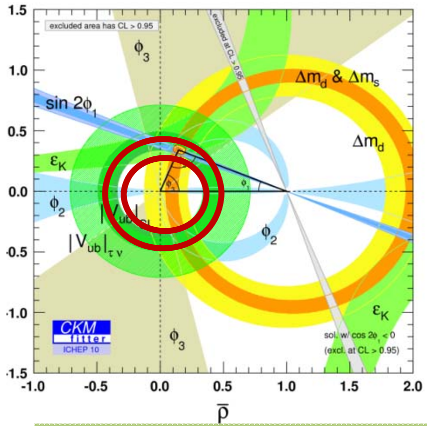
$\phi_3 = (68\ ^{+13}_{-14})$ degrees



Note that B factories were not built to measure ϕ_3

It turned out much better than planned!

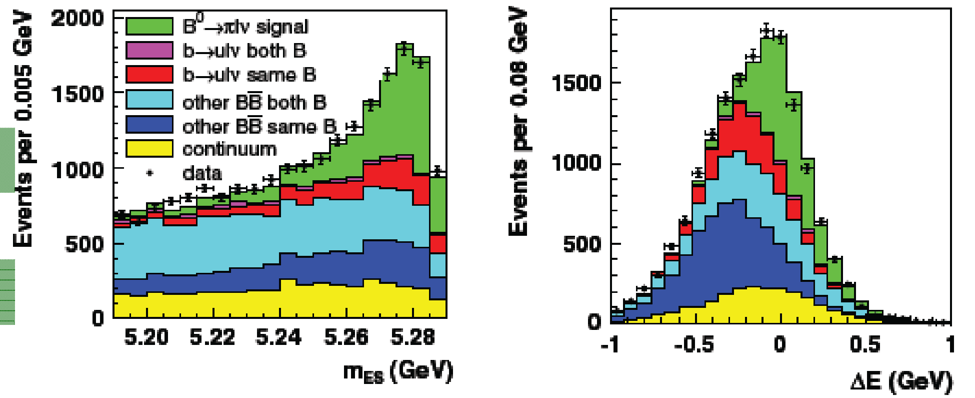
This is not the last word from B factories, analyses still to be finalized...



$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu$ exclusive decays

Yield: 2d fit in $M_{bc}=M_{ES}$ and ΔE, bins of q^2

$$m_{bc} = \sqrt{E^2_{beam} - |\vec{p_\pi} + \vec{p_\ell} + \vec{p_\nu}|^2}$$
$$\Delta E = E_{beam} - (E_\pi + E_\ell + E_\nu)$$



$\mathcal{B}=(1.41\pm0.05\pm0.07)\cdot10^{-4}$

BaBar, PRD83, 032007 (2011)

$\mathcal{B}=(1.42\pm0.05\pm0.07)\cdot10^{-4}$

BaBar, PRD83, 052011 (2011)

$\mathcal{B}=(1.49\pm0.04\pm0.07)\cdot10^{-4}$

Belle, arXiv:1012:0090

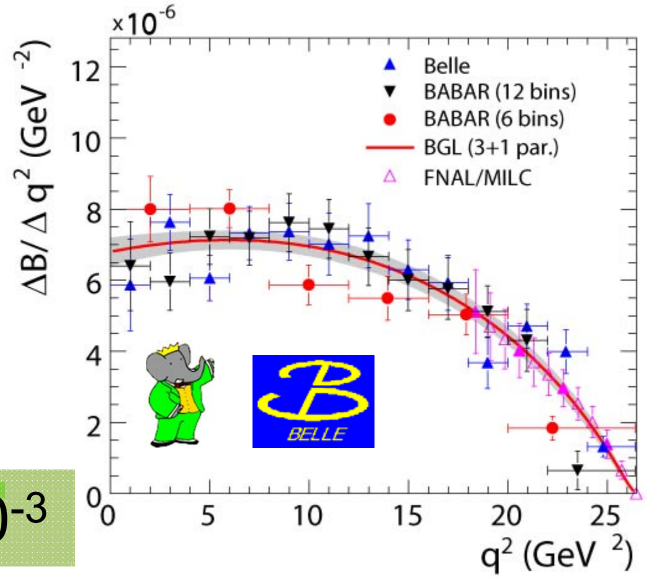
$|V_{ub}|$ extraction: fit data + LQCD points in

$$q^2 = (p_\ell + p_\nu)^2 = (p_B - p_\pi)^2$$

BaBar + FNAL/MILC $|V_{ub}| = (3.13\pm0.12\pm0.28)\cdot10^{-3}$

Belle + FNAL/MILC $|V_{ub}| = (3.43\pm0.33)\cdot10^{-3}$

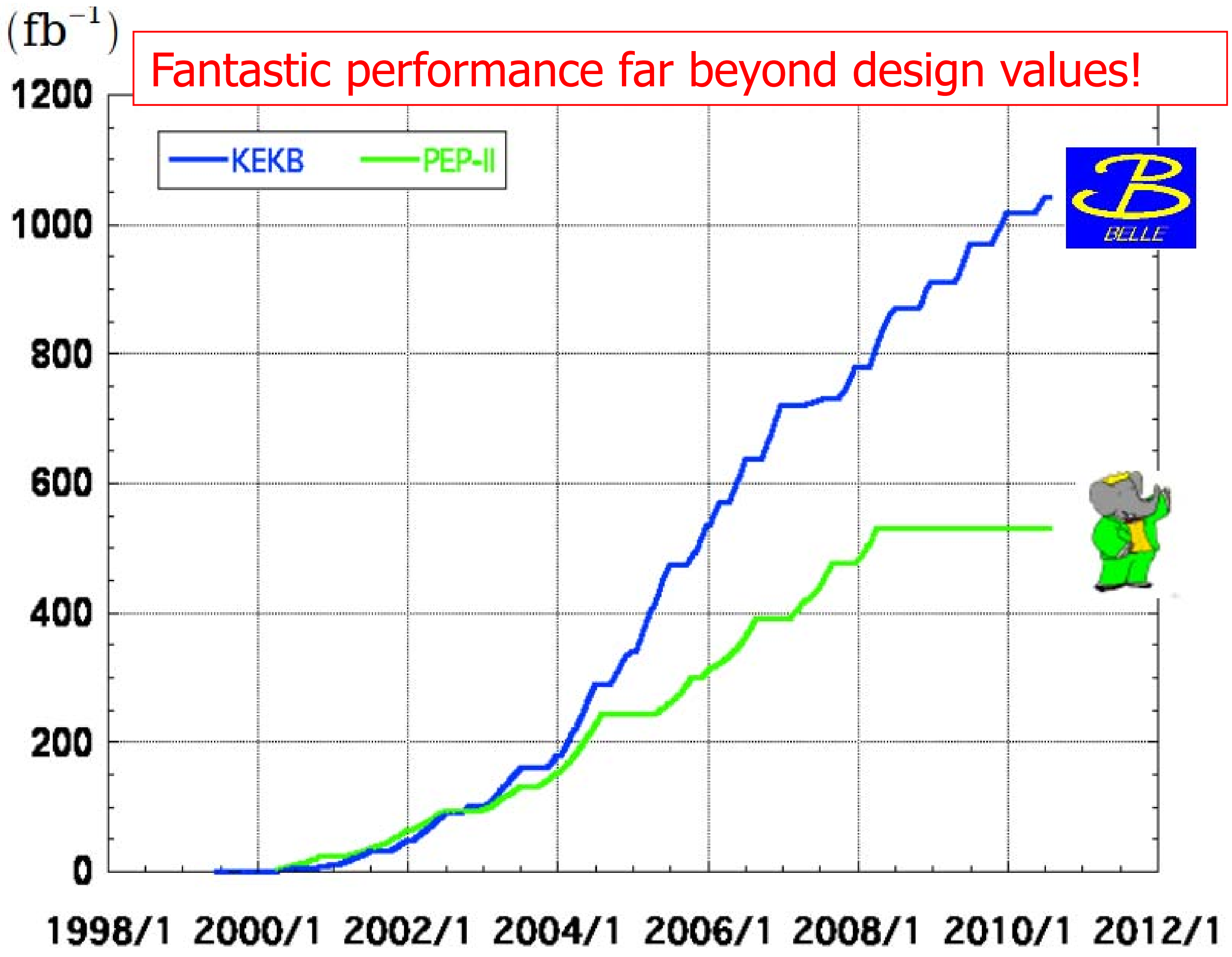
Belle + BaBar + FNAL/MILC $|V_{ub}| = (3.26 \pm 0.30)\cdot10^{-3}$



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

Integrated luminosity at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

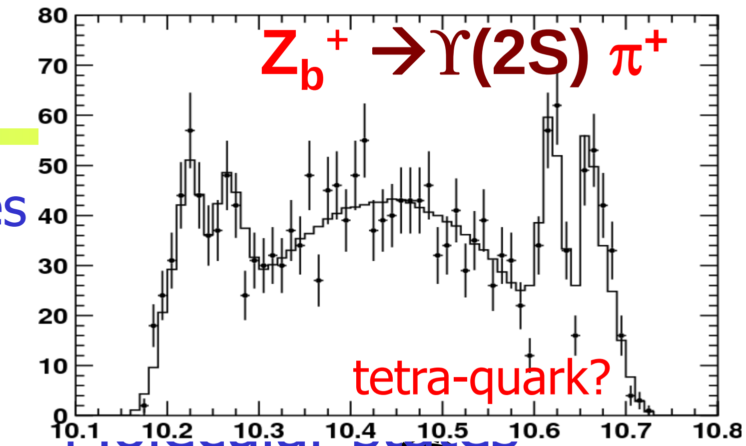
$\Upsilon(2S)$: 14 fb^{-1}

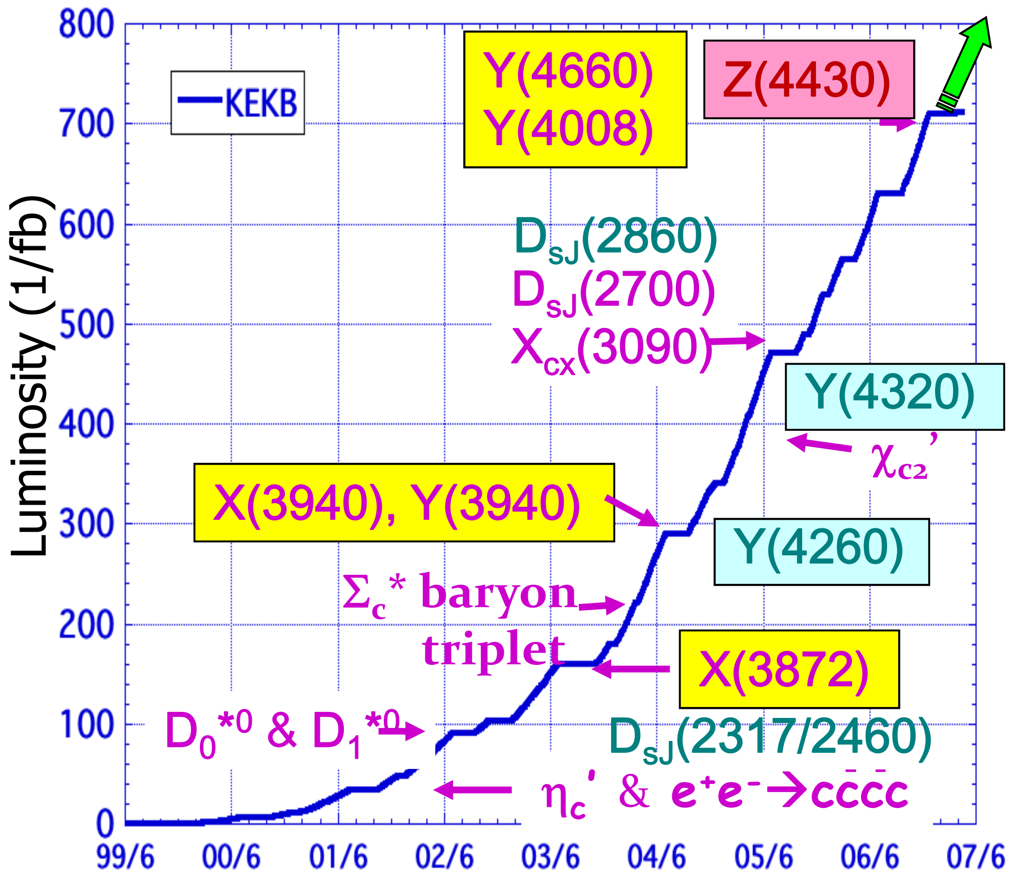
Off resonance:

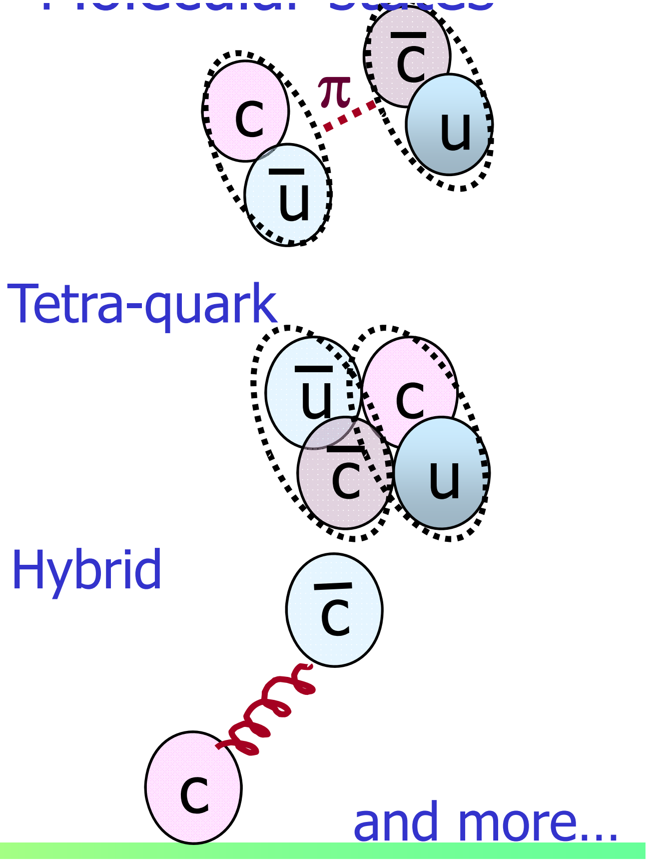
~ 54 fb^{-1}

New hadrons at B-factories

Discoveries of many new hadrons at B-factories
class of hadrons beyond the ordinary mesons.







What next?

B factories → is SM with the KM scheme right?

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

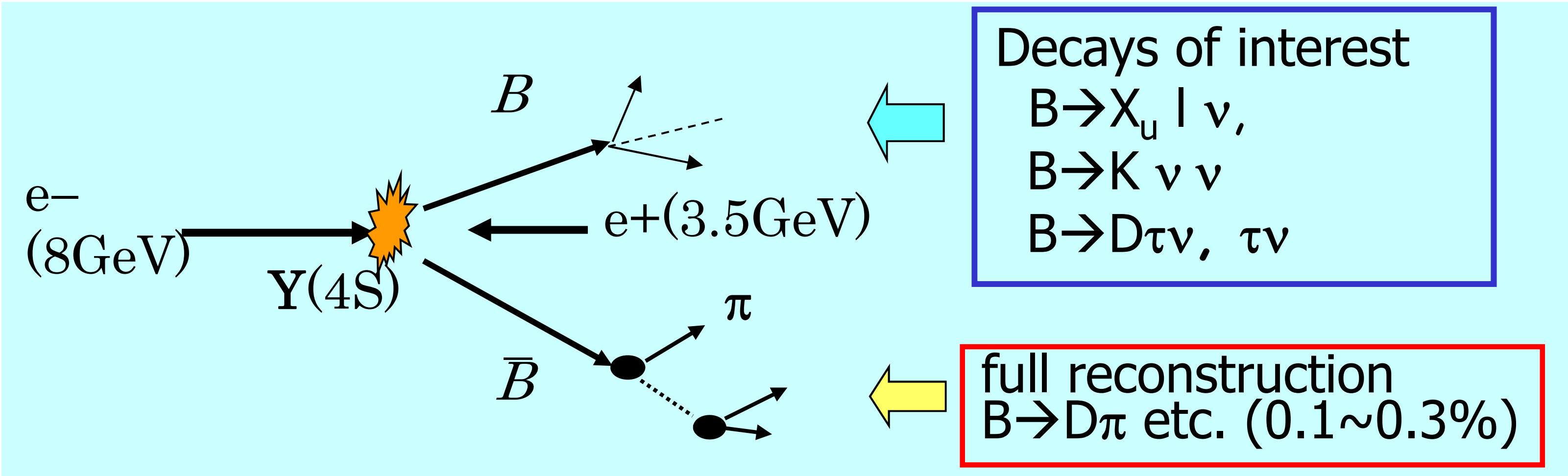
→ Need much more data (two orders!) because the SM worked so well until now → Super B factory

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

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

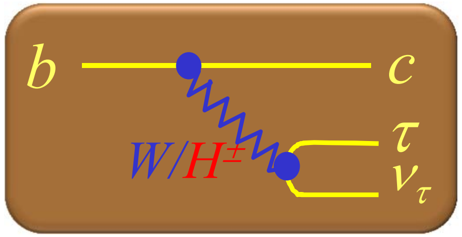


→ Offline B meson beam!

Powerful tool for B decays with neutrinos

B→D^(*)τν

Semileptonic decay sensitive to charged Higgs



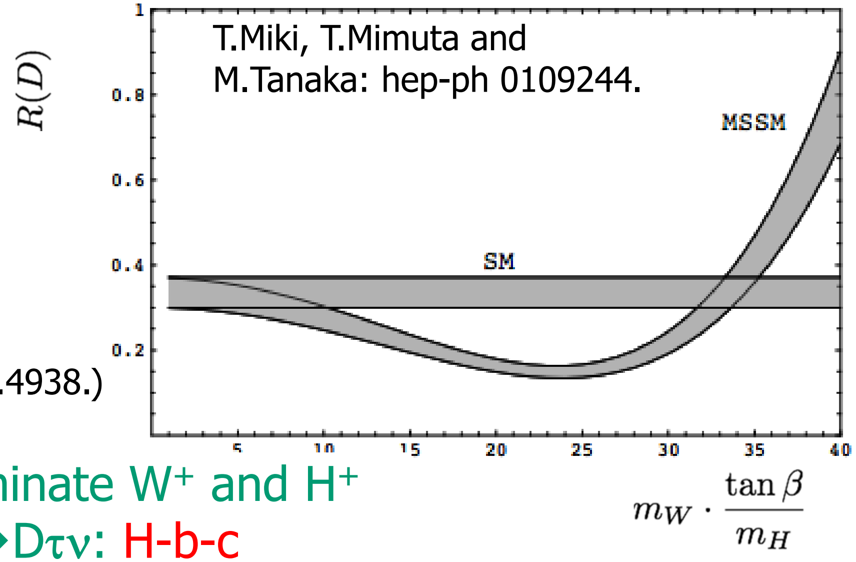
Ratio of τ to μ,e could be reduced/enhanced significantly

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

Complementary and competitive with B→τν

1. Smaller theoretical uncertainty of R(D)
   (For B→τν,
   There is O(10%) f_B uncertainty from lattice QCD)

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



3. Differential distributions can be used to discriminate W^+ and H^+
4. Sensitive to different vertex B→τ ν: H-b-u, B→Dτν: H-b-c
   (LHC experiments sensitive to H-b-t)

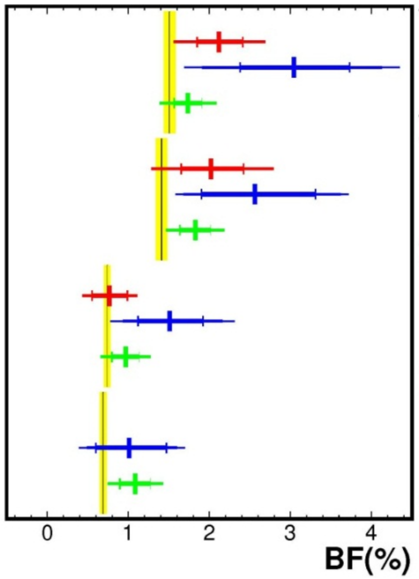
Advantage of B factories!

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

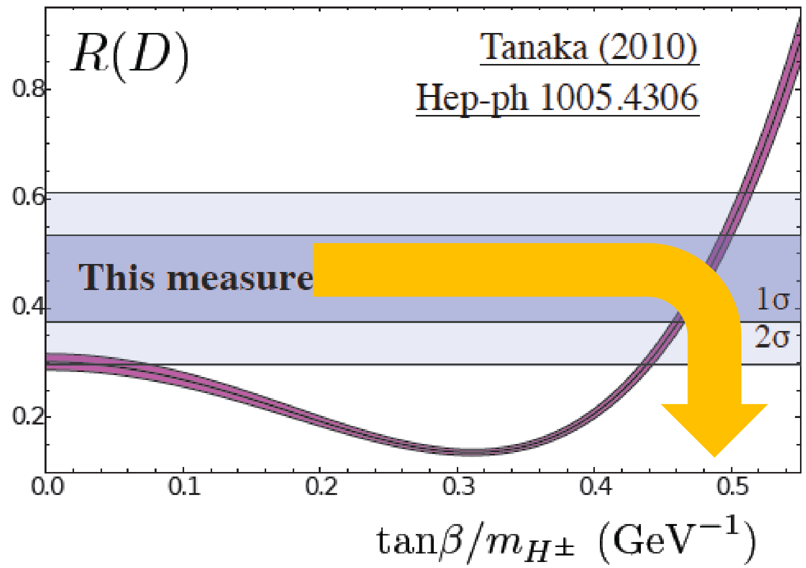
$B \to D^{(*)} \tau\nu$ decays

This summer: First 5σ observation (BaBar) of $B \to D\tau\nu$ decays (exclusive hadron tag data)

Belle inclusive tag,
Belle exclusive tag,
Babar excusive tag (summer 2011)
compared to the
SM prediction



$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$	(1.73±0.17±0.18)%
$B^0 \to D^{*-}\tau^+\nu_\tau$	(1.82±0.19±0.17)%
$B^+ \to \overline{D}^0\tau^+\nu_\tau$	(0.96±0.17±0.14)%
$B^0 \to D^-\tau^+\nu_\tau$	(1.08±0.19±0.15)%

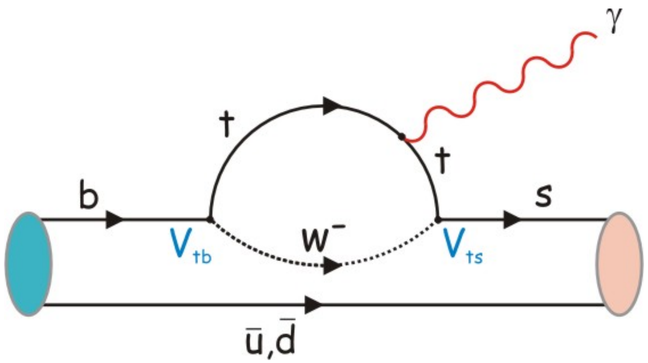


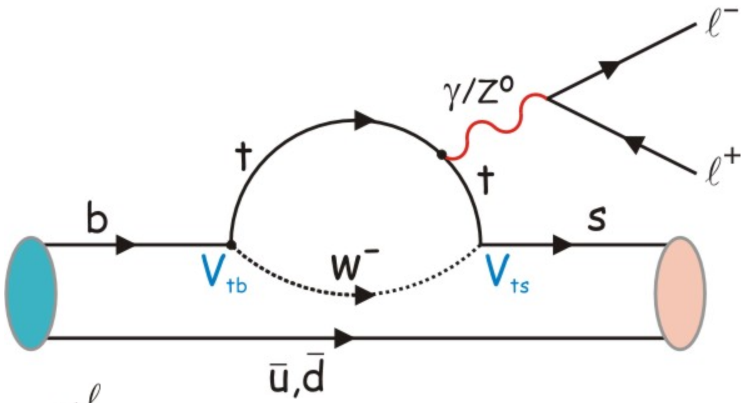
All values higher than SM predictions →

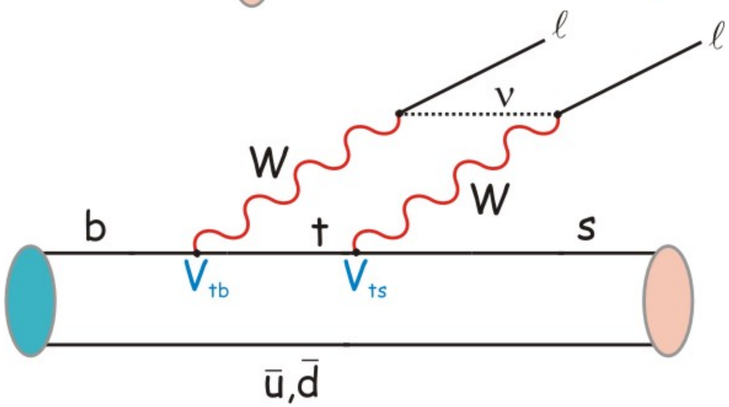
→ A very interesting limit on charged Higgs

Why 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.







A difference in the direct violation of CP symmetry in B⁺ and B⁰ 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

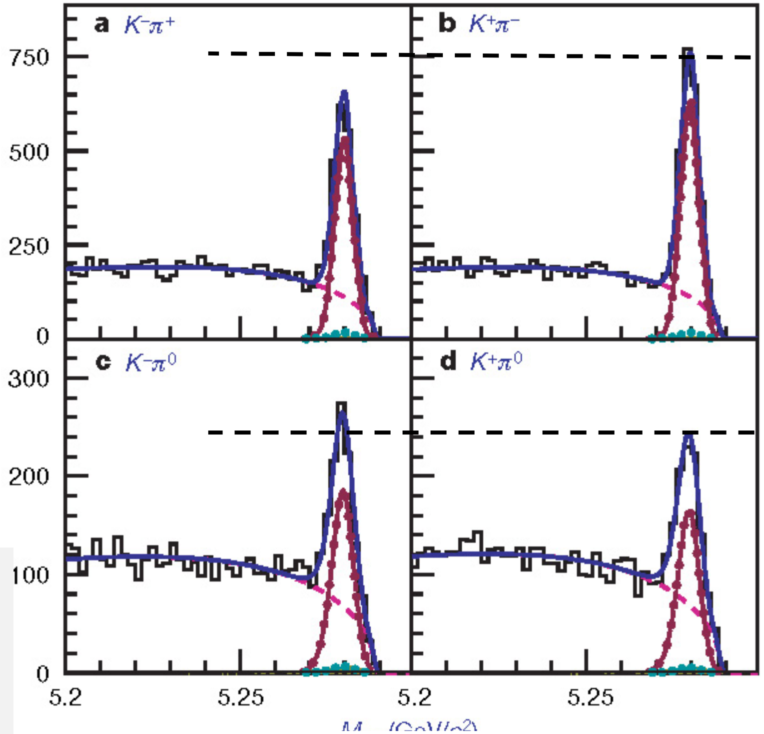
The Belle Collaboration*

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 B⁰ decays

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



Measure:

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

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

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

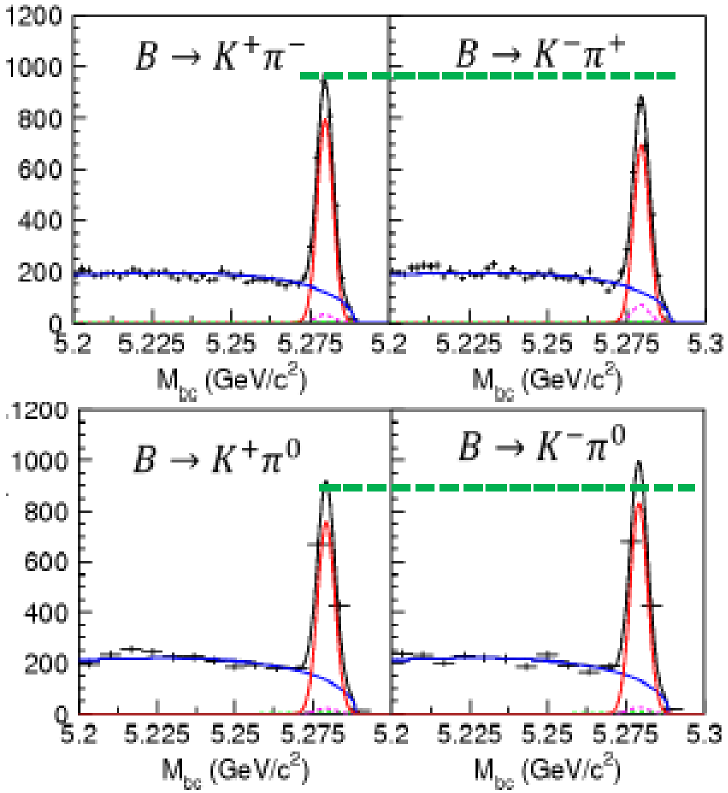
~1 in 10^5 B mesons decays in this decay mode

Belle, Nature 452, 332 (2008)

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

Direct CP violation difference in $B \rightarrow K^+\pi^-$ and $K^+\pi^0$

Update 2011



$\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$

Update the 2008 result with the full data set and improved reconstruction - ~2x more data

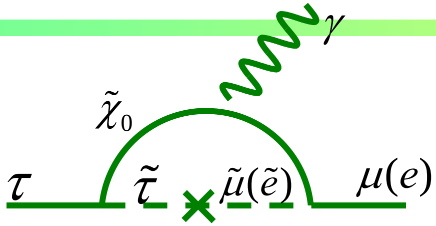
$$A_{cp}(K^{\pm}\pi^{0}) = +0.043 \pm 0.024 \pm 0.002$$
$$A_{cp}(K^{\pm}\pi^{\mp}) = -0.069 \pm 0.014 \pm 0.007$$

Belle preliminary:

$$\Delta A_{K\pi} = +0.112 \pm 0.028 \ @4\sigma$$

LFV and New Physics

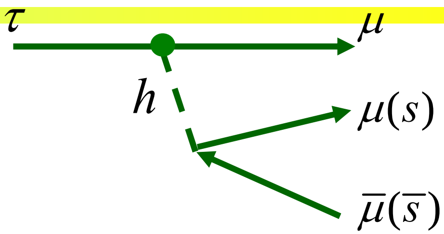
$\tau \to l\gamma$



- SUSY + Seasaw $(m^2_{\tilde{l}})_{23(13)}$
- Large LFV Br($\tau \to \mu\gamma$)=O($10^{-7\sim9}$)

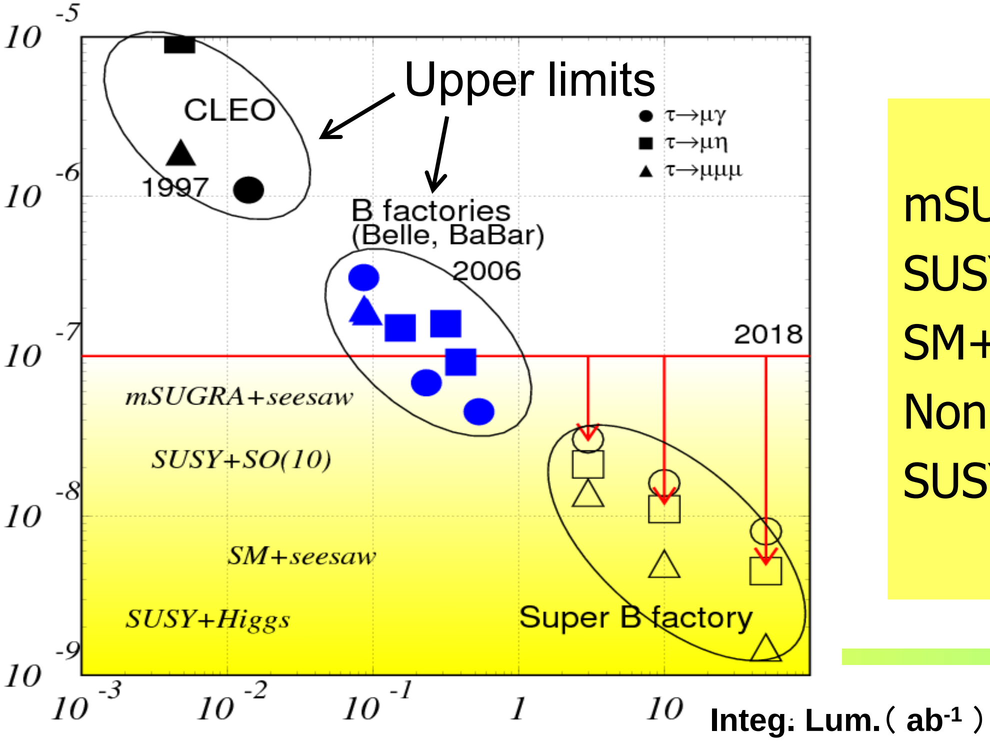
$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

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



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

$$Br(\tau \to 3\mu) = 4\times10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}}\right)\left(\frac{\tan\beta}{60}\right)^6\left(\frac{100GeV}{m_A}\right)^4$$



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}

B Physics @ Υ(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 @ Υ(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

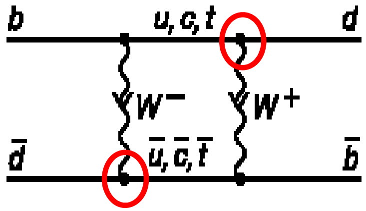
Physics at a Super B Factory

- 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).

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



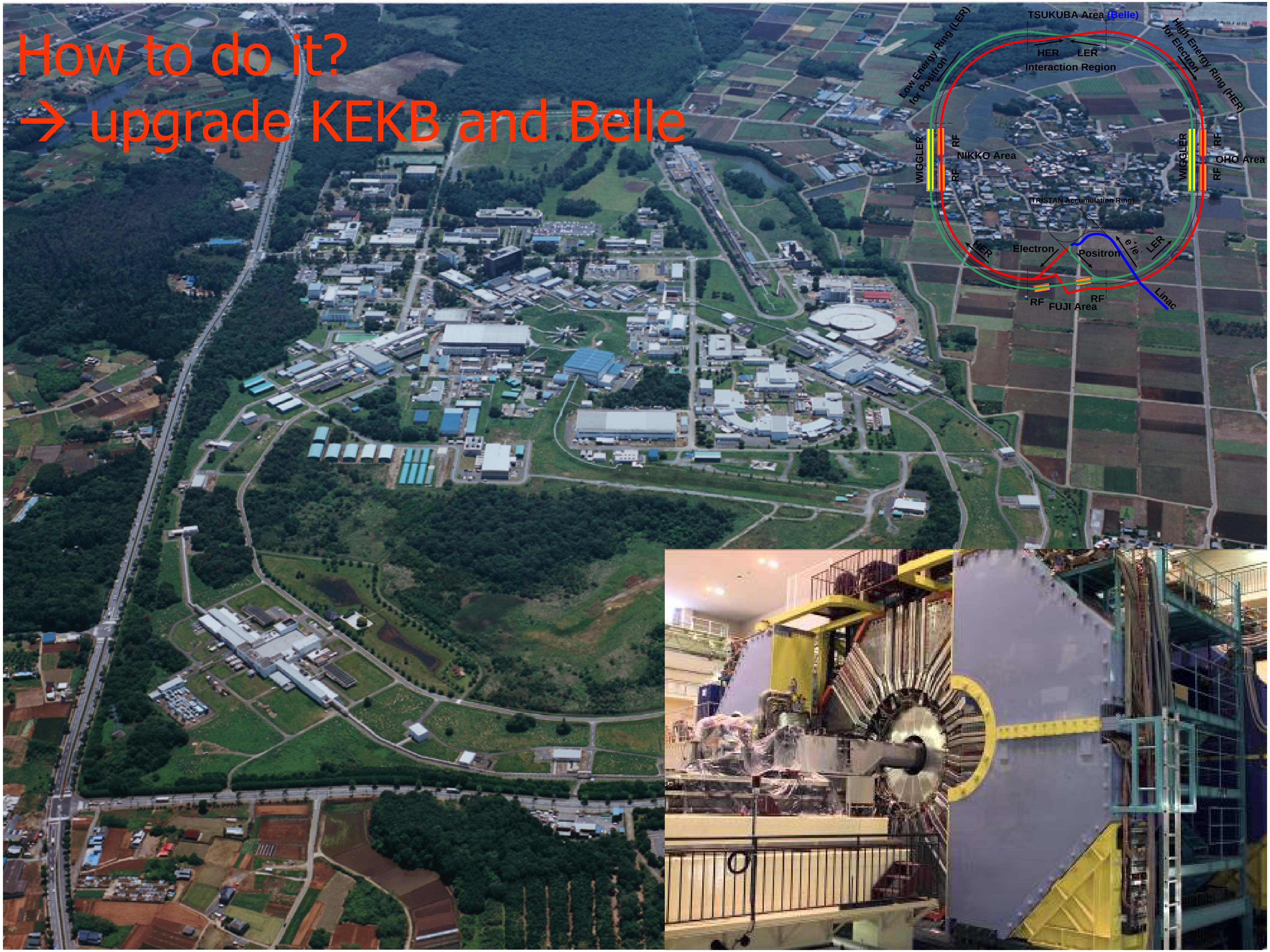
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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

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

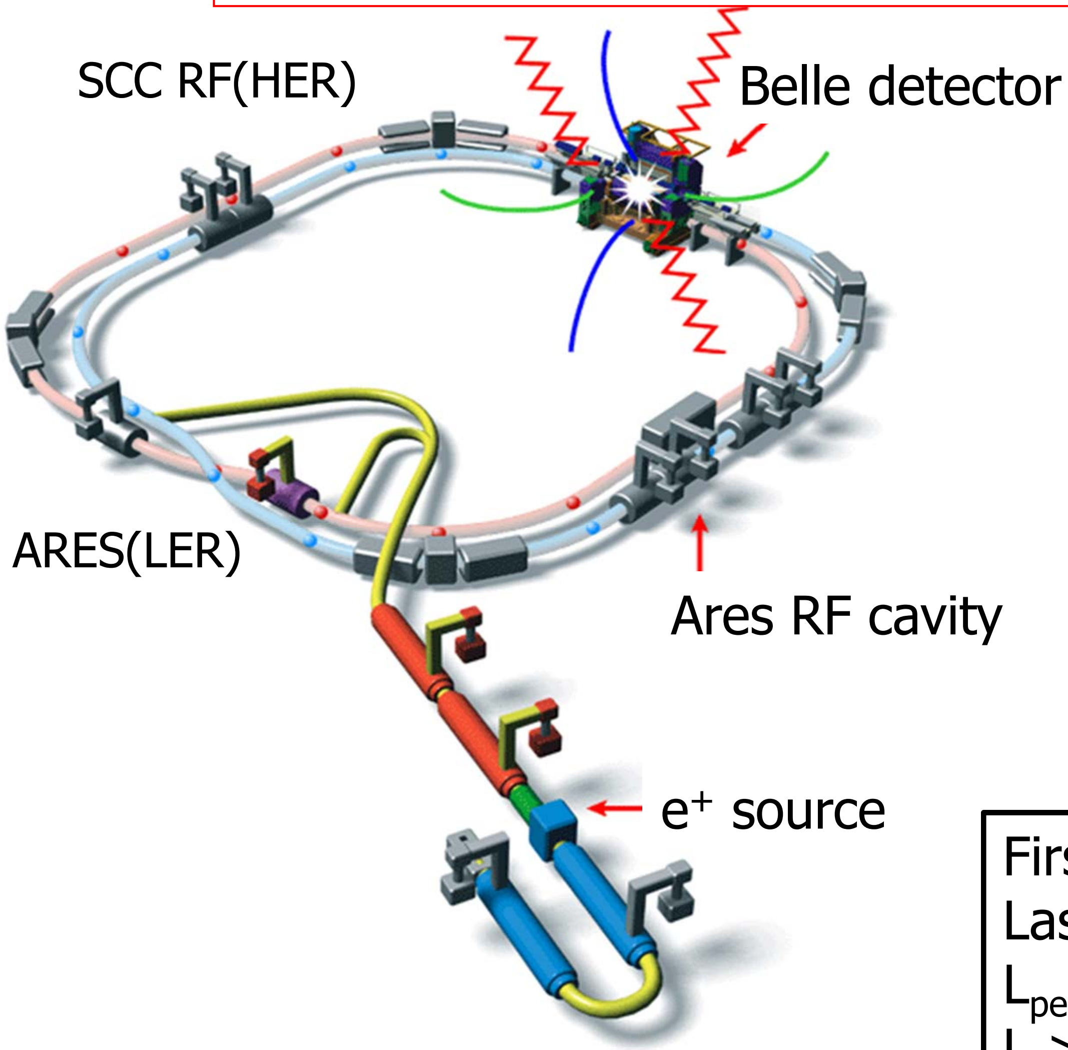
Recent update of the physics reach with 50 ab^{-1} (75 ab^{-1}):
Physics at Super B Factory (Belle II authors + guests)
hep-ex > arXiv:1002.5012
SuperB Progress Reports: Physics (SuperB authors + guests)
hep-ex > arXiv:1008.1541

How to do it?
→ upgrade KEKB and Belle



The KEKB Collider

Fantastic performance far beyond design values!



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

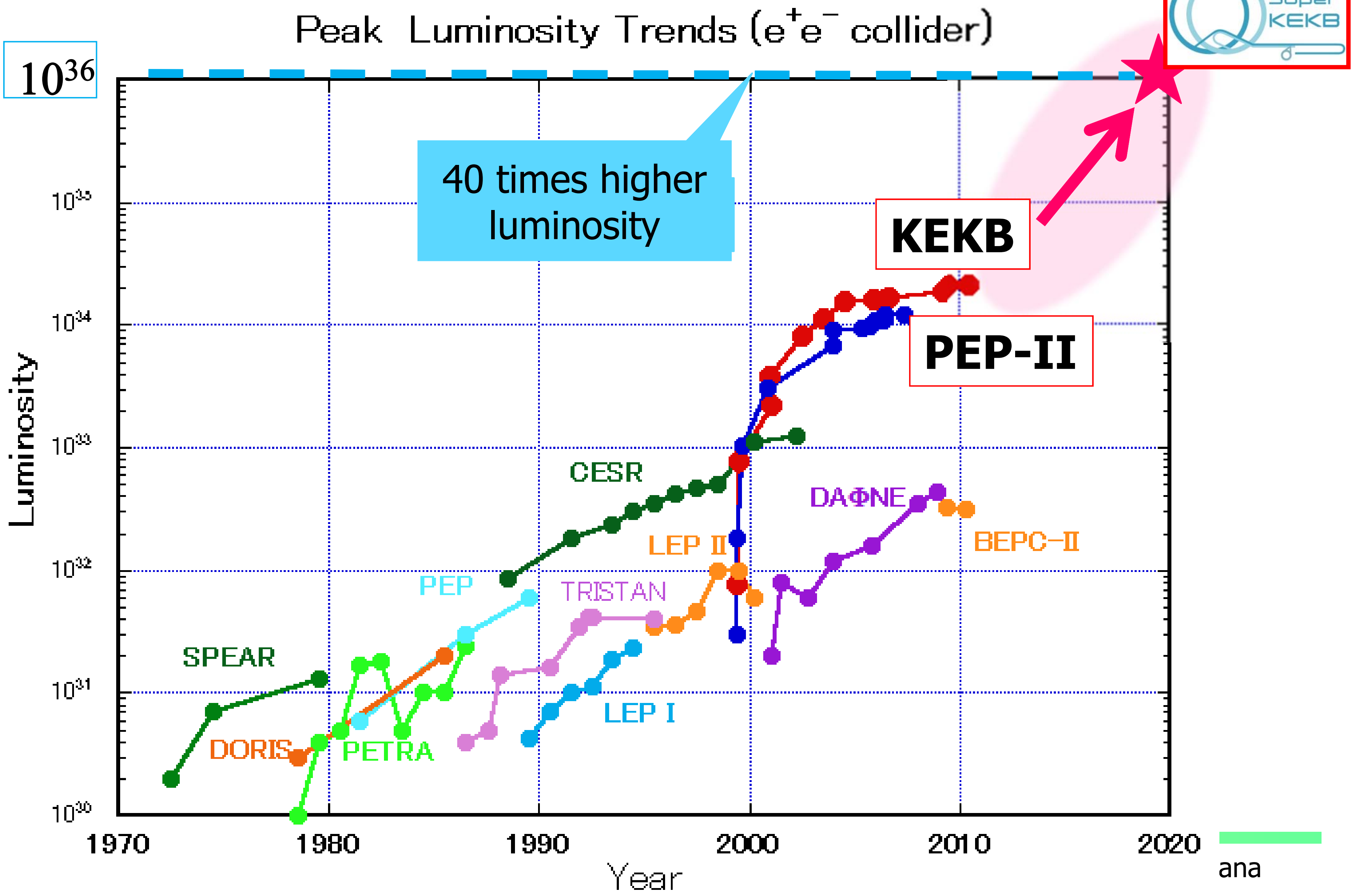
Peak luminosity (WR!) :

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
$L_{peak} = 2.1 \times 10^{34}/cm^2/s$
$L > 1ab^{-1}$

SuperKEKB is the intensity frontier

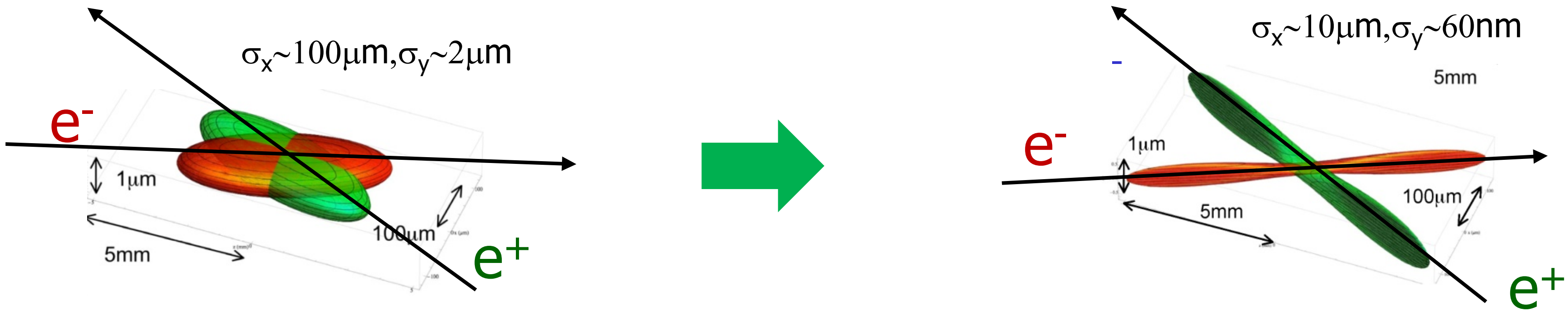


ana

How big is a nano-beam ?

How to go from an excellent accelerator with world record performance – KEKB – to a 40x times better, more intense facility?

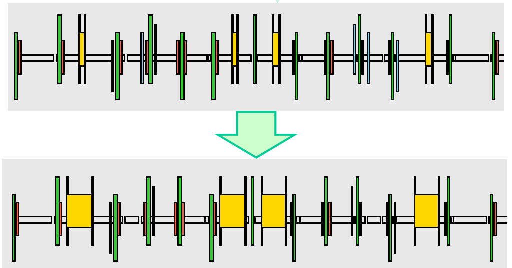
In KEKB, colliding electron and positron beams are much thinner than the human hair...



... For a 40x increase in intensity you have to make the beam as thin as 100 atomic layers!

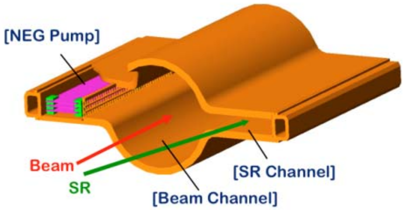
KEKB to SuperKEKB

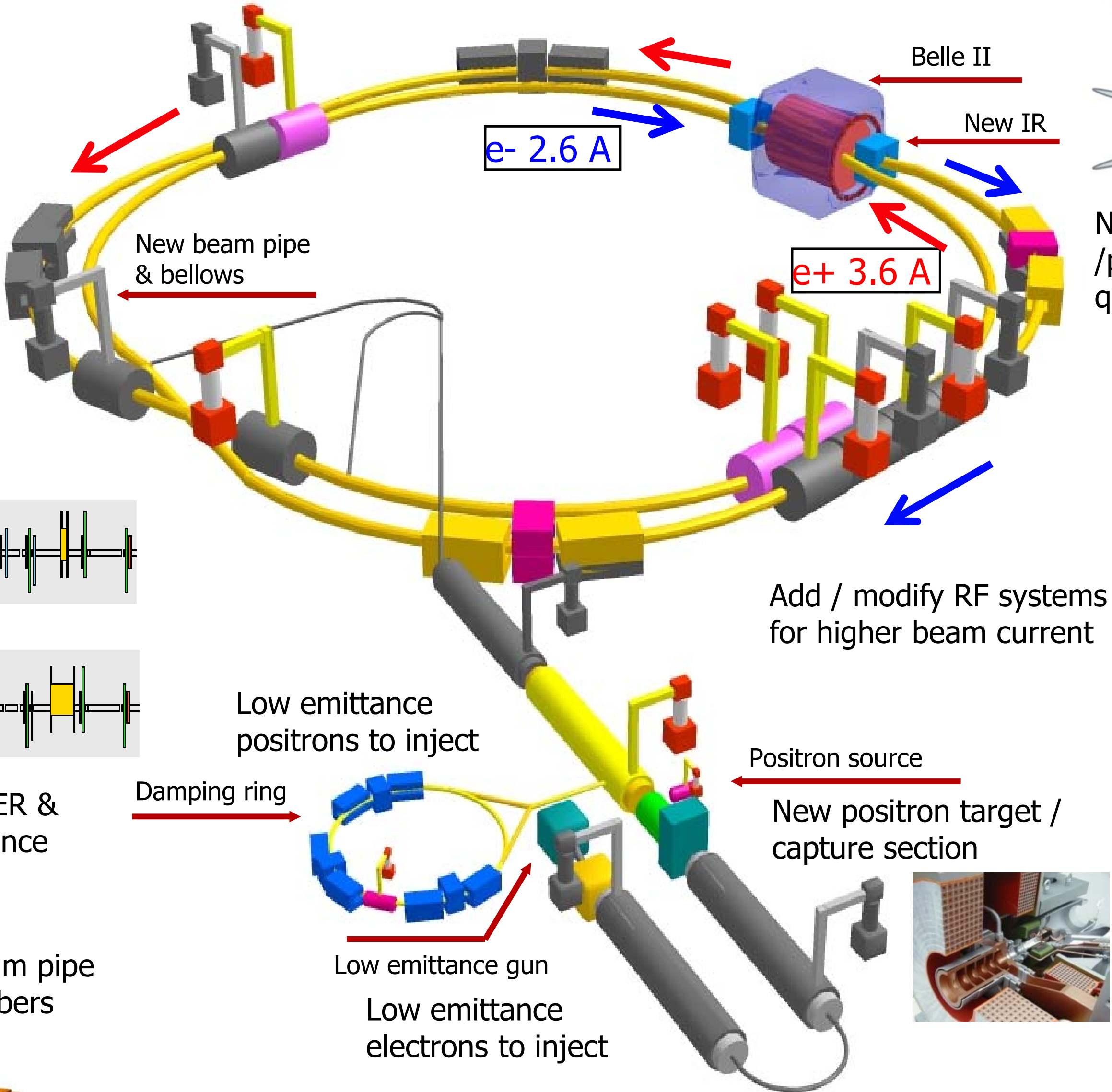
Replace short dipoles
with longer ones (LER)



Redesign the lattices of HER &
LER to squeeze the emittance

TiN-coated beam pipe
with antechambers

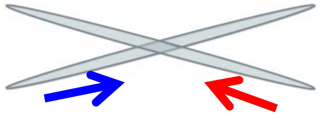




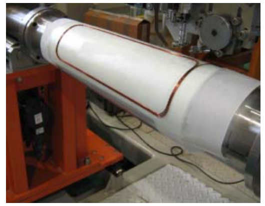
Low emittance
positrons to inject

Low emittance
electrons to inject

Colliding bunches



New superconducting
/permanent final focusing
quads near the IP



Add / modify RF systems
for higher beam current

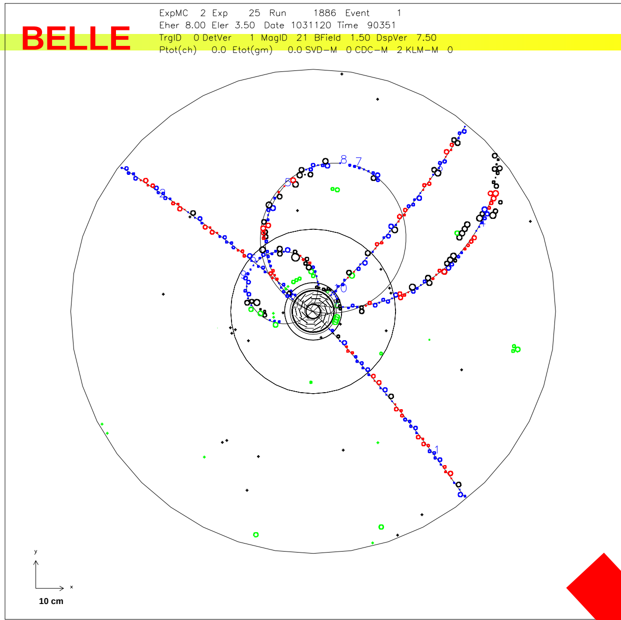
New positron target /
capture section

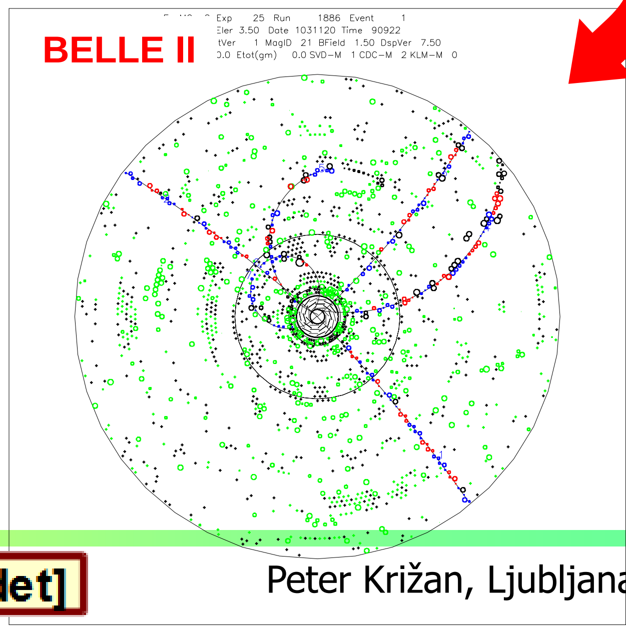
To get x40 higher interaction rate

Need to build a new detector to handle higher backgrounds

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 ← sμμ recon. eff.
  - hermeticity ← ν "reconstruction"



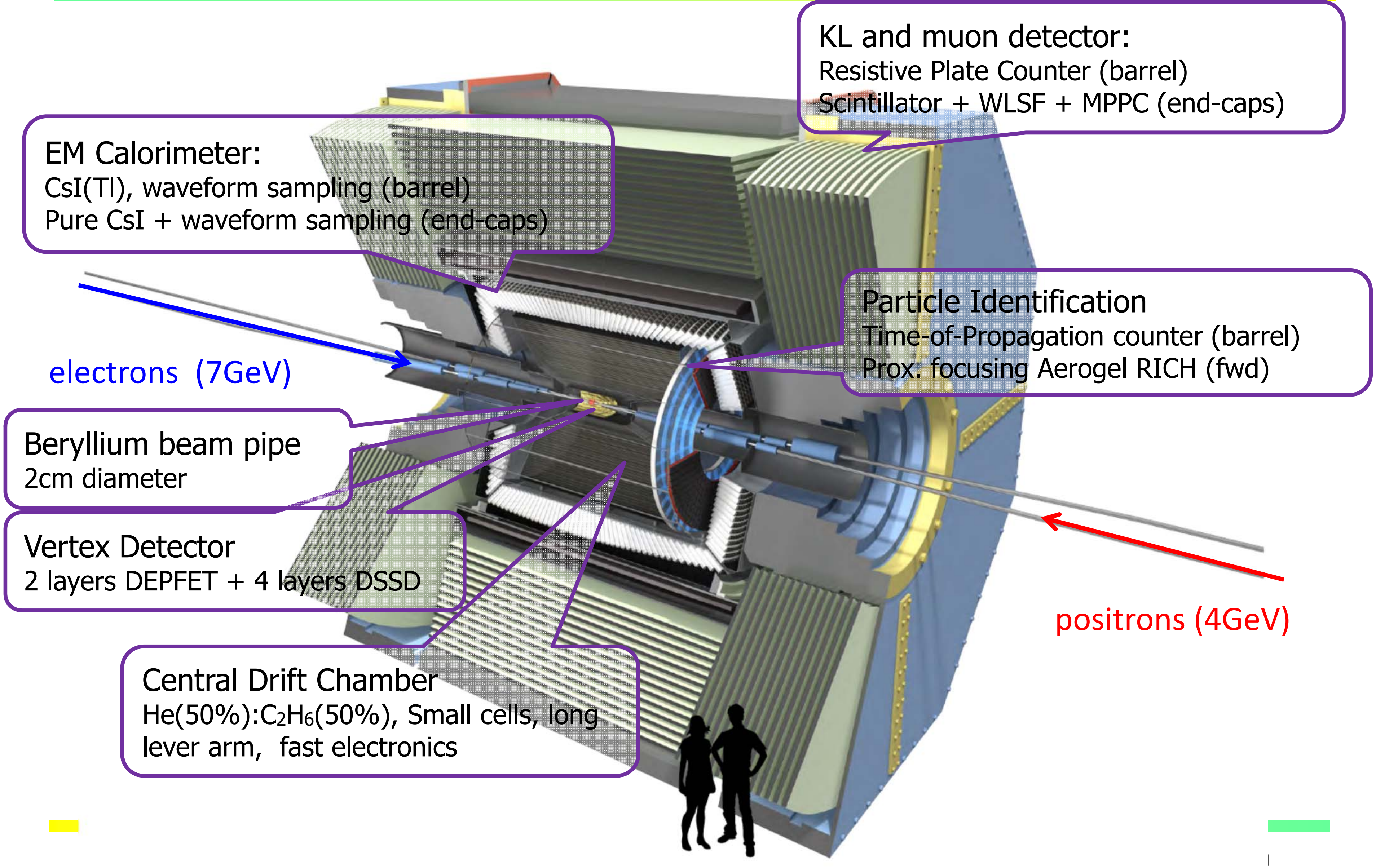


Have to employ and develop very advanced technologies to build such an appartus!

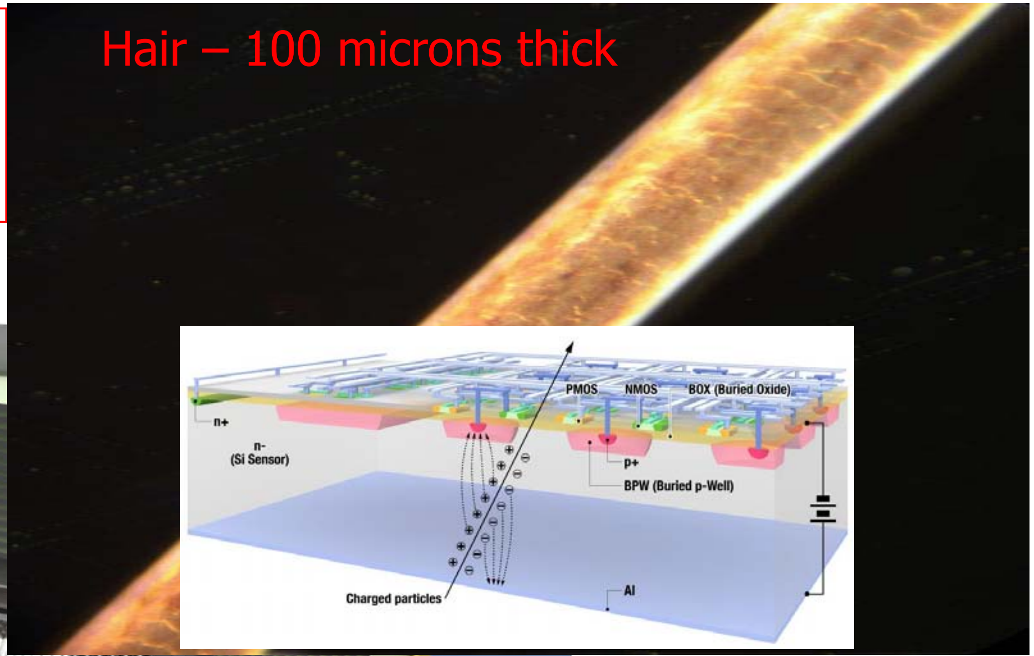
→

TDR published arXiv:1011.0352v1 [physics.ins-det]

Belle II Detector

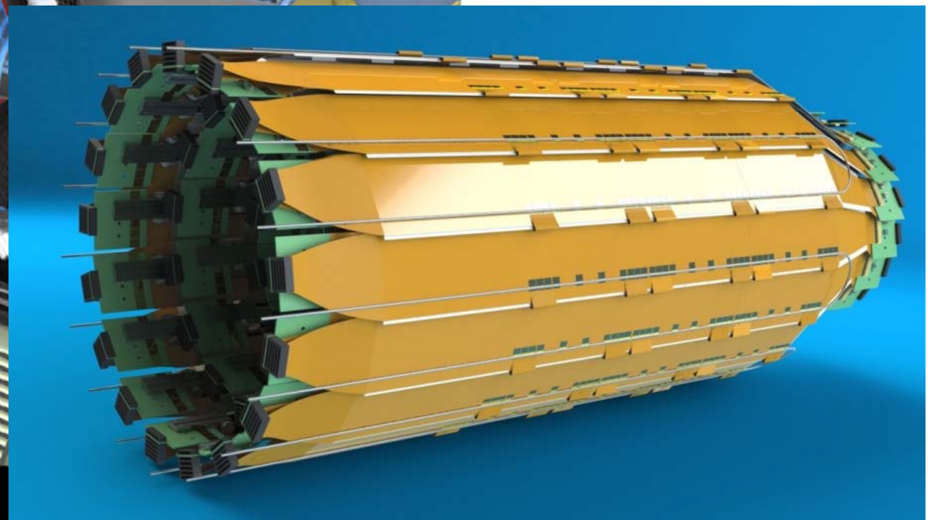


Determine the reaction point position with a fantastic precision - extremly delicate elements

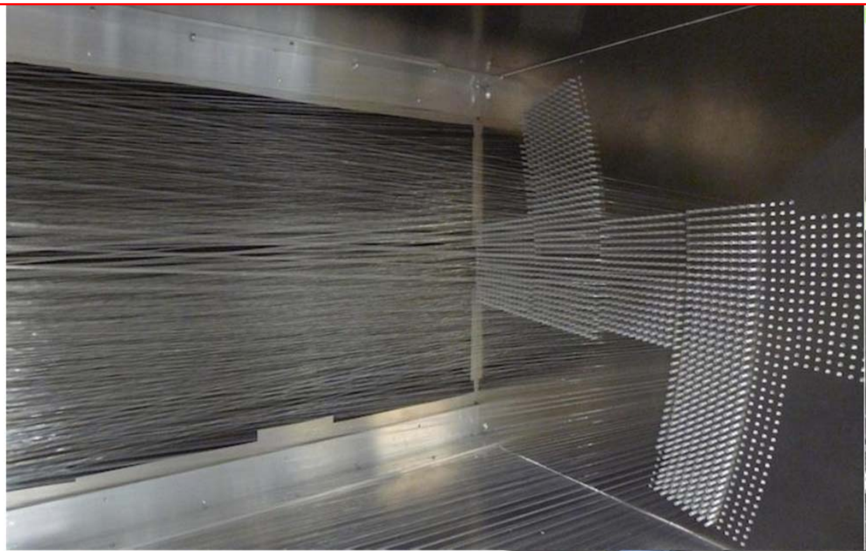


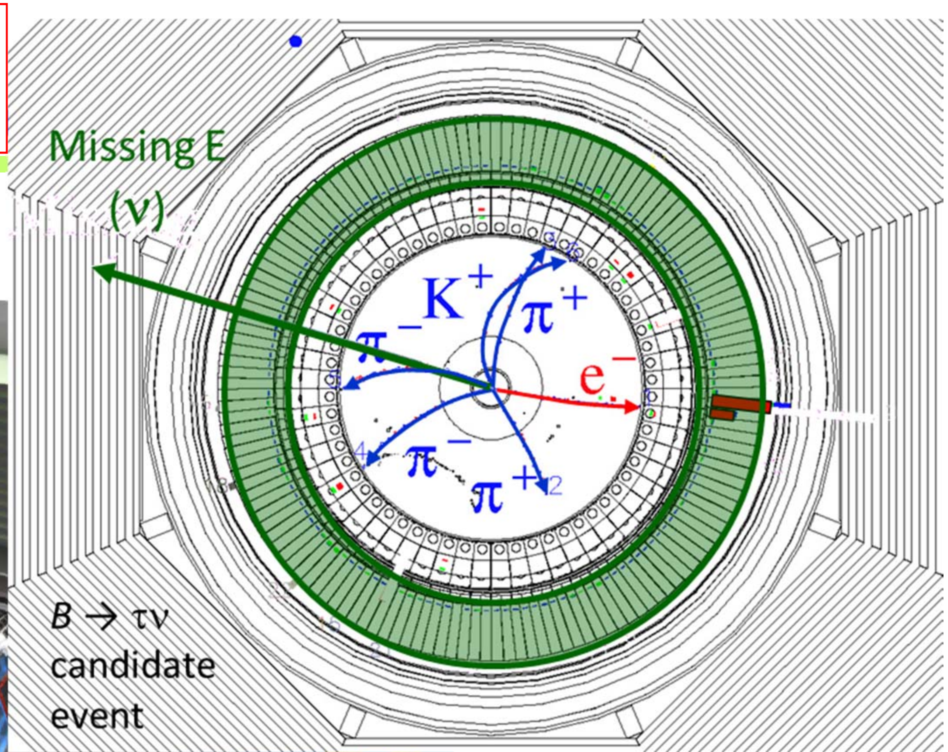
Beryllium beam pipe
2cm diameter

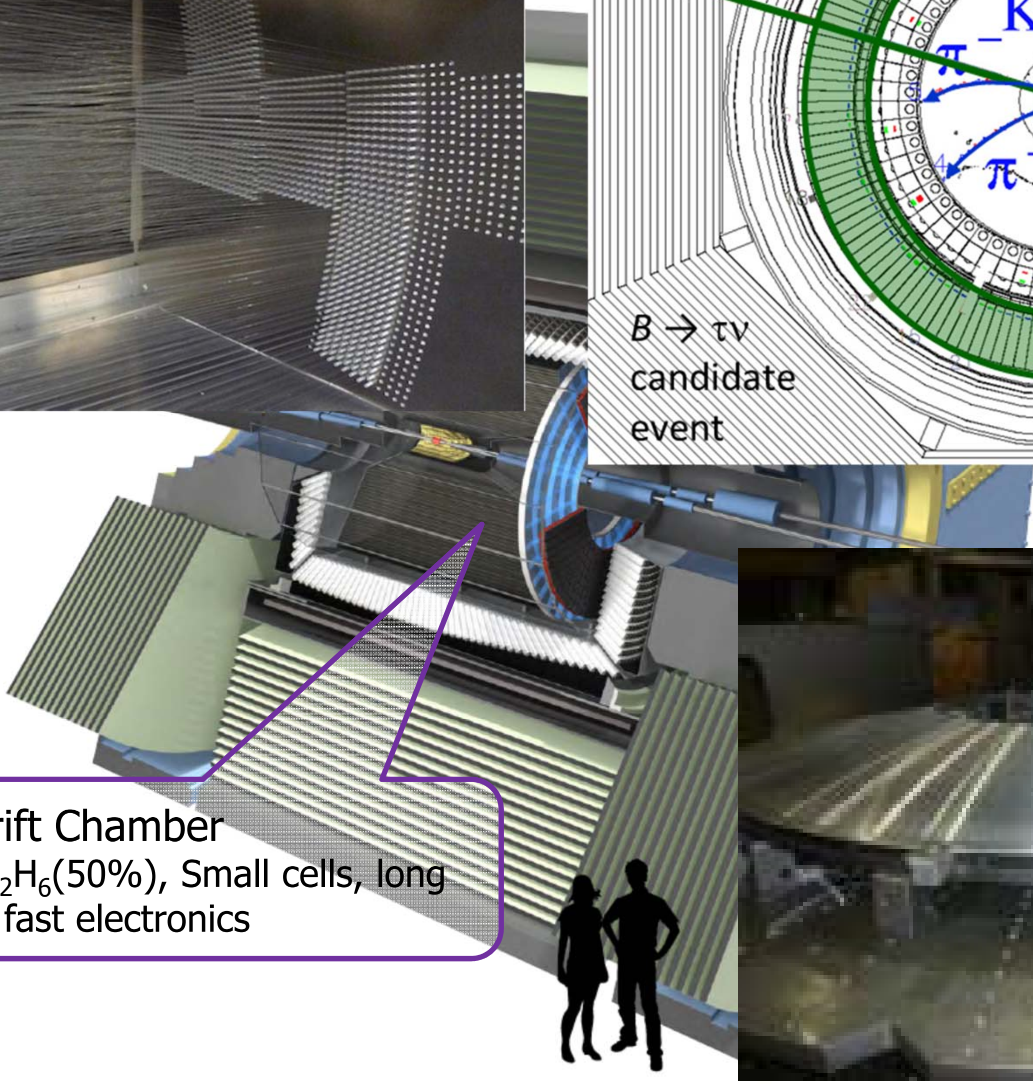
Vertex Detector
2 layers DEPFET + 4 layers DSSD



Tracking charged particles in magnetic field – measure their momenta

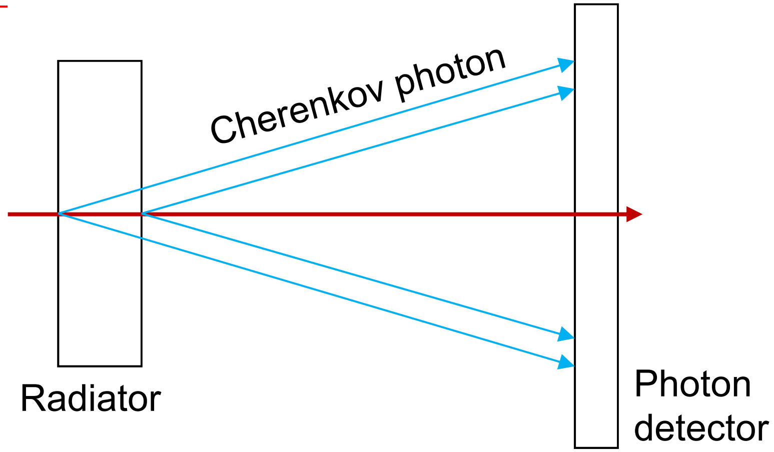


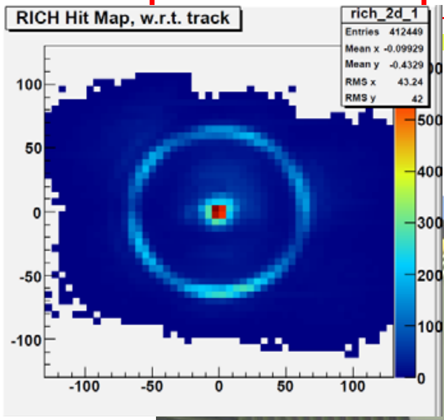


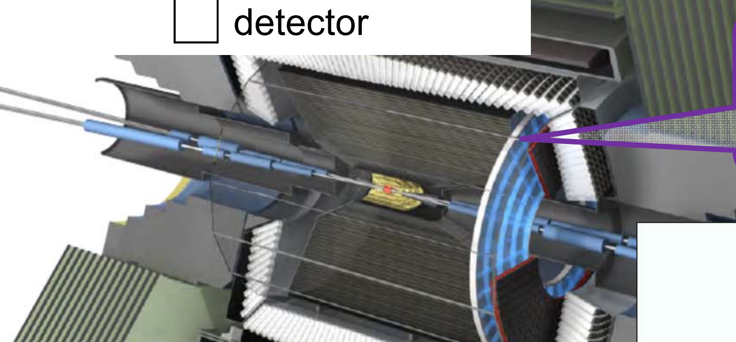


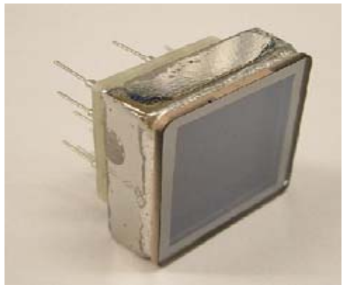
Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

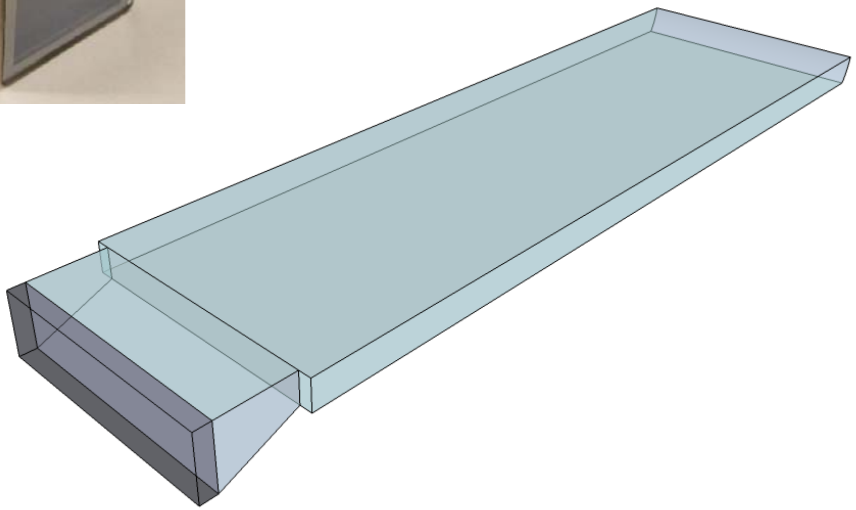
Use Cherenkov effect: light emitted by a particle faster than velocity of light in a medium - like a shock wave from a supersonic airplane!

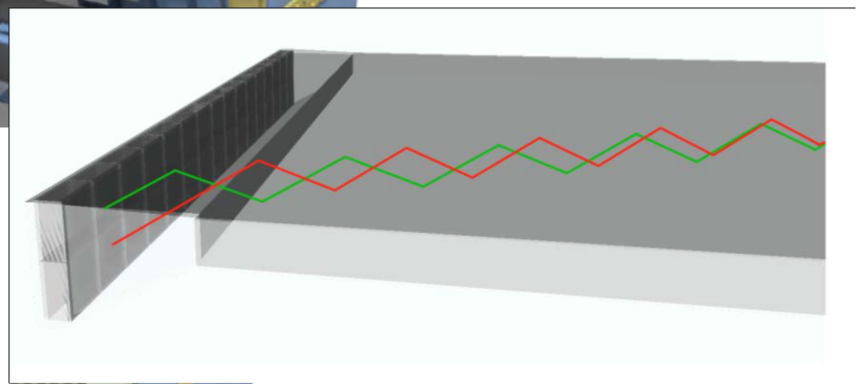




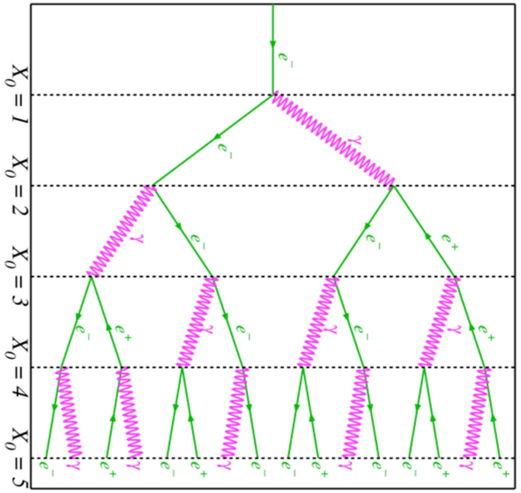




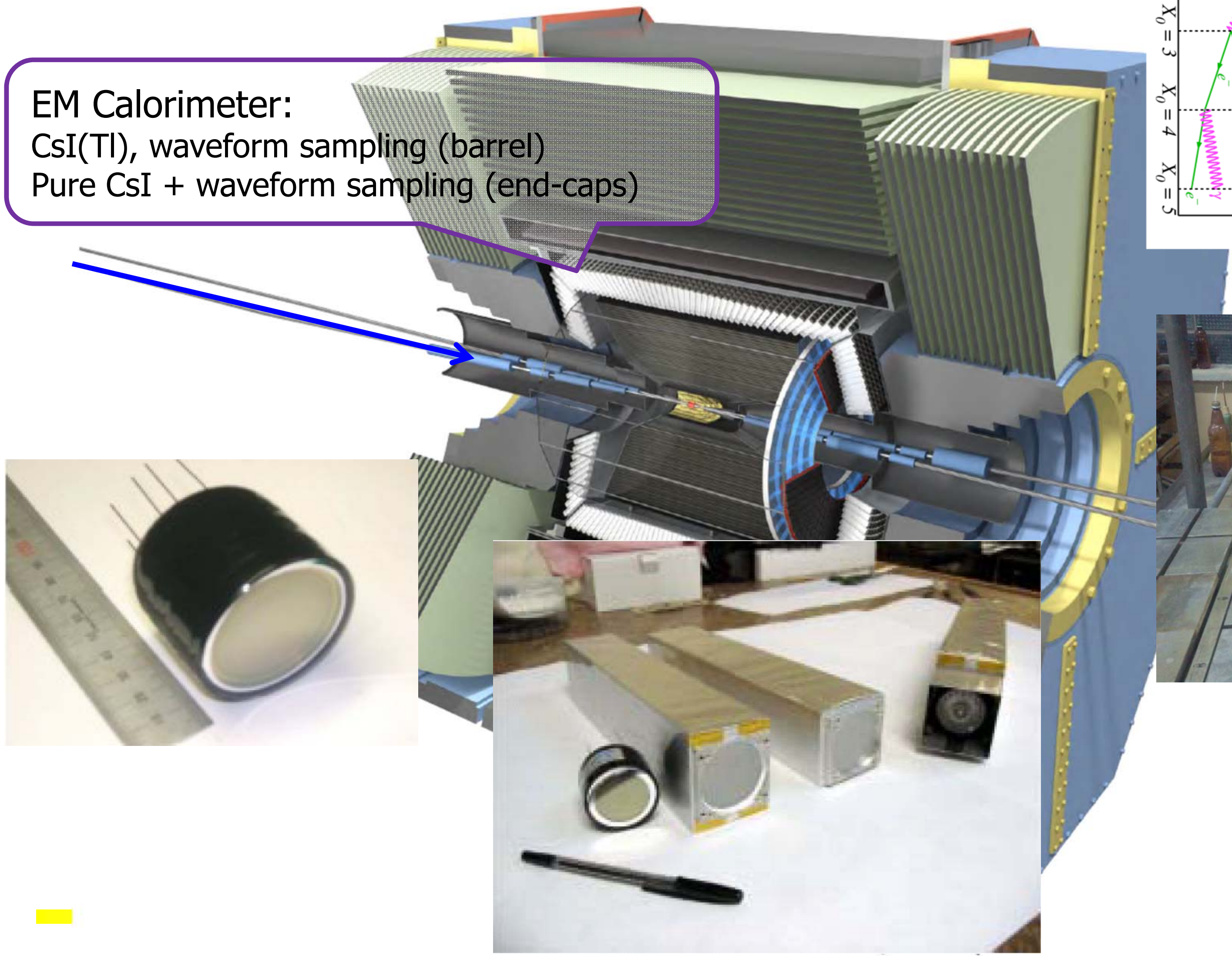




Detect electrons and high energy gamma rays by leting them produce a shower in a heavy crystal

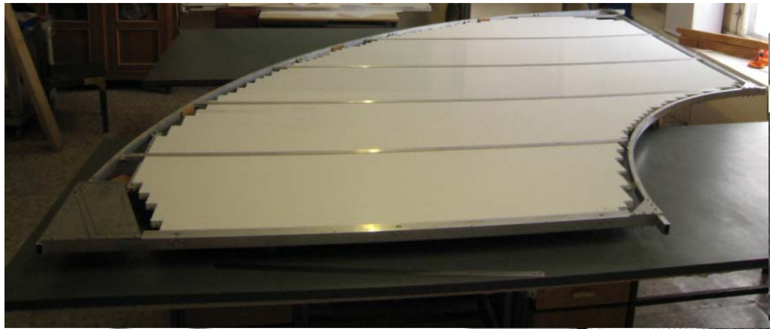


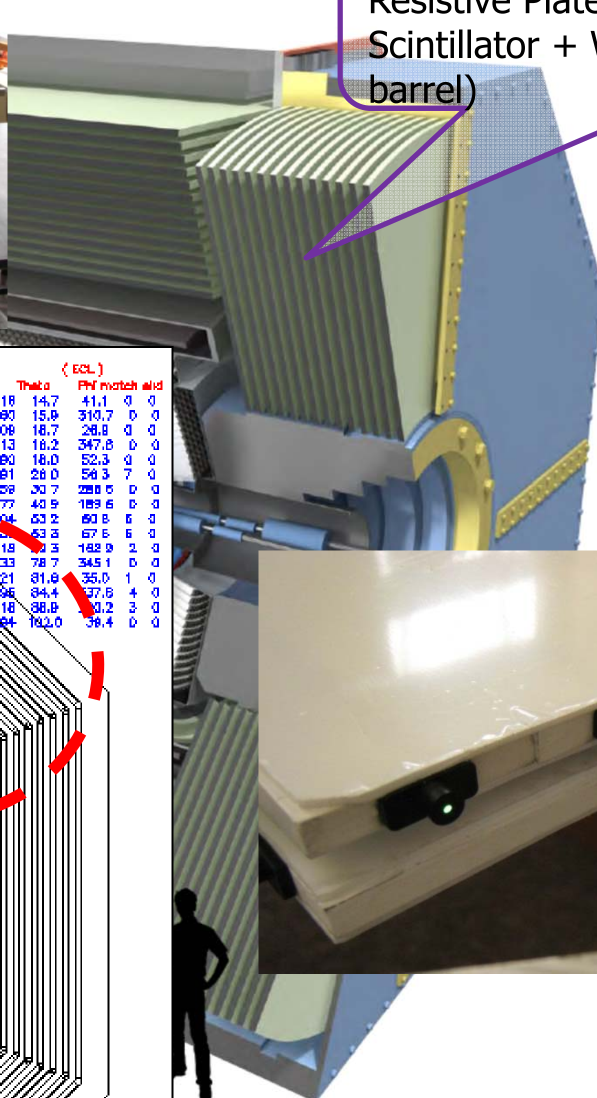
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

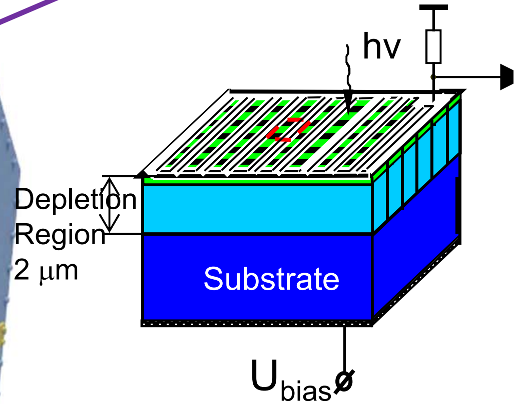


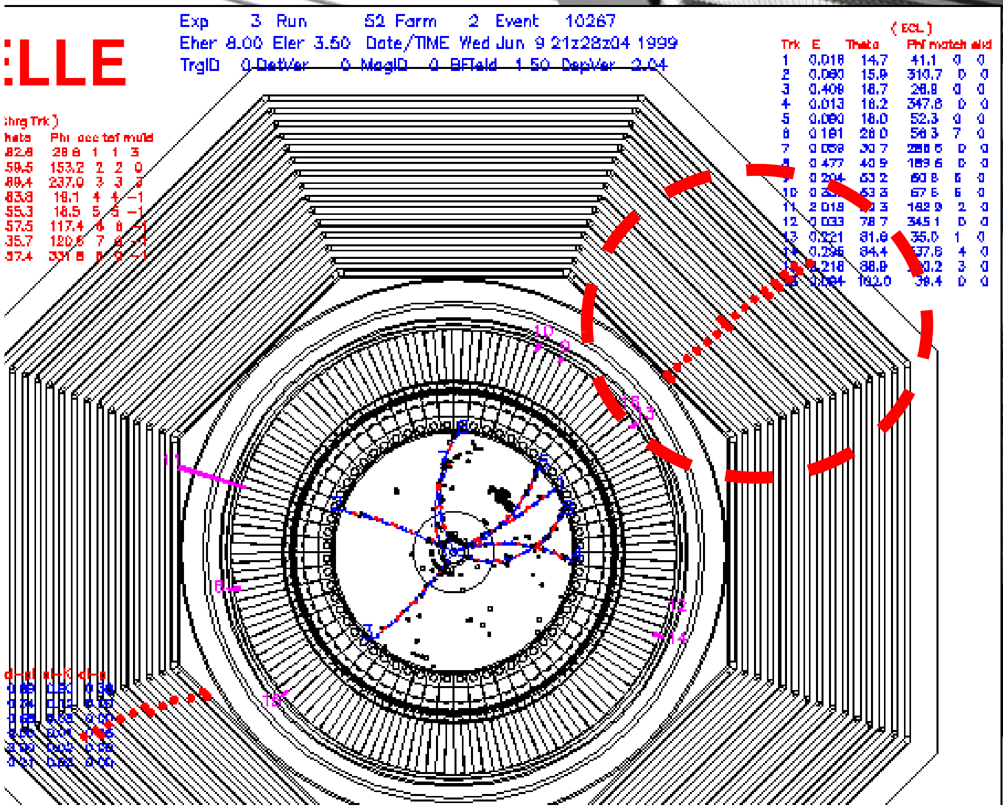
Detect muons: particles that penetrate 1m of iron

K$_L$ and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps + barrel)







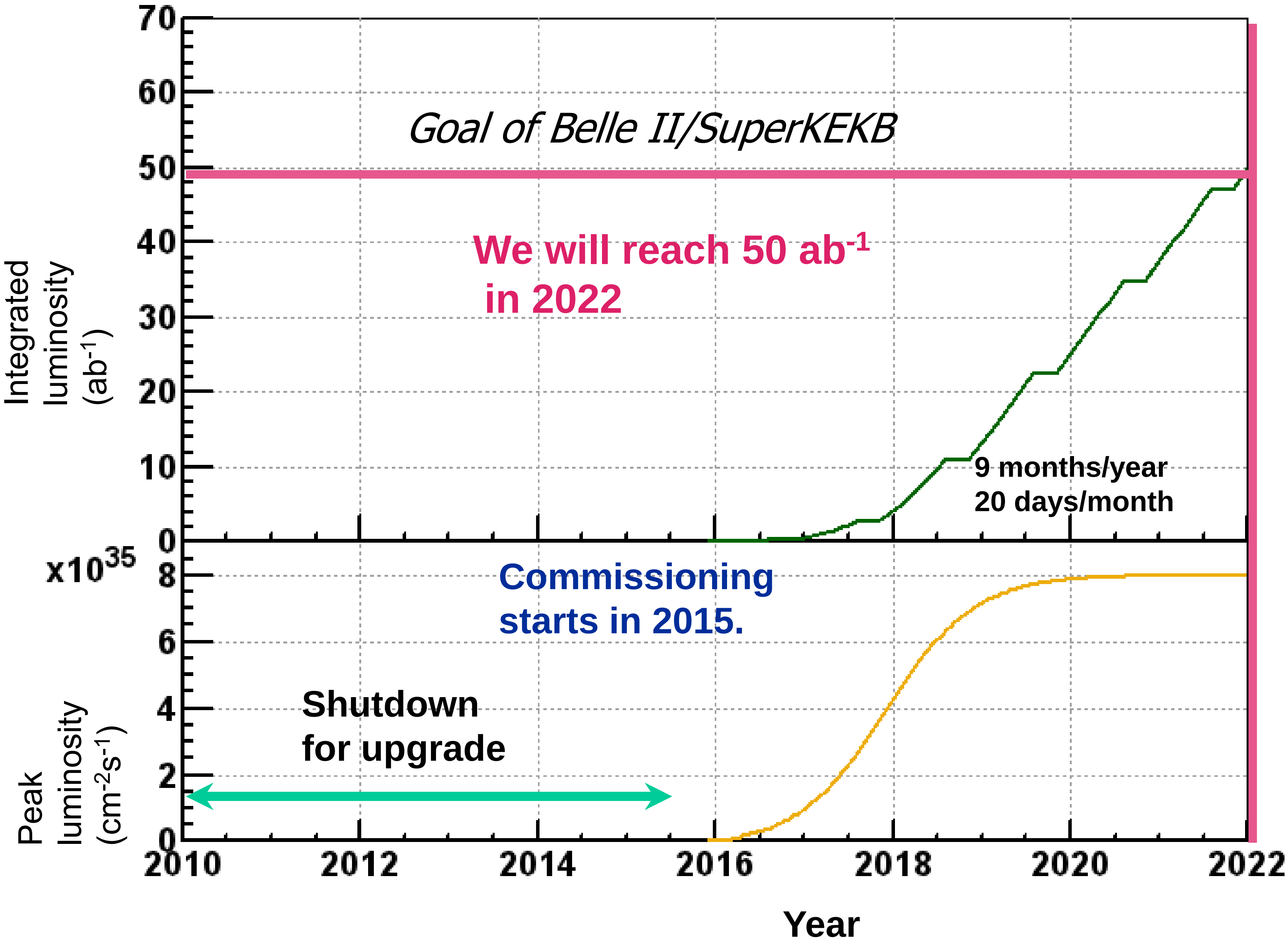


a

The Belle II Collaboration

A very strong group of ~400 highly motivated scientists!

Schedule (Beam starts in Fall 2014)



Conclusion

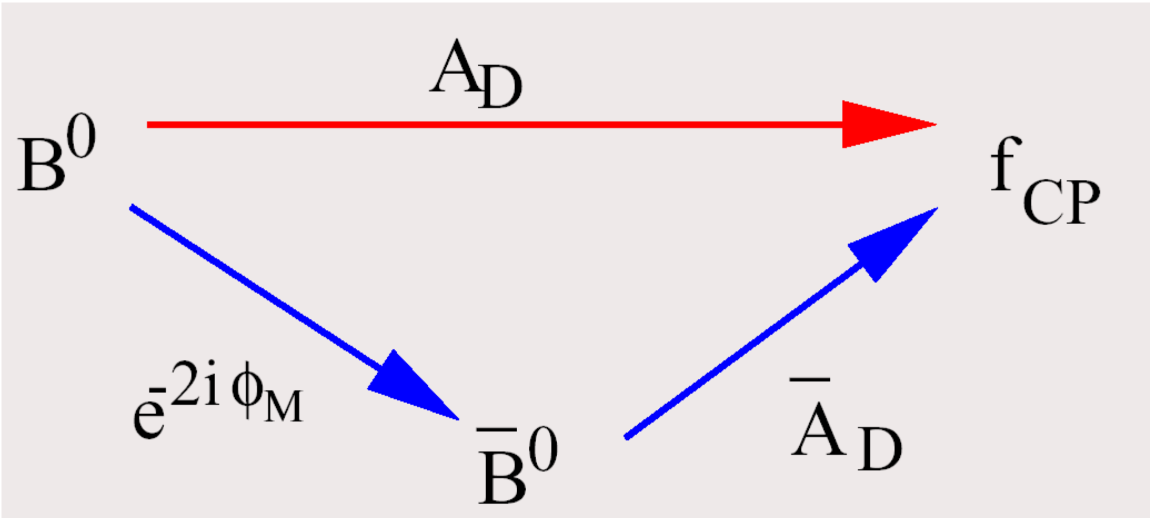
- KEKB has proven to be an excellent tool for flavour physics, with reliable long term operation, breaking world records, and surpassing its design perfomance by a factor of two.
- Major upgrade at KEK in 2010-14 → SuperKEKB+Belle II, with 40x larger event rates, construction started
- Expect a new, exciting era of discoveries, complementary to the LHC

Back-up slides

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 $J/\psi K_S$

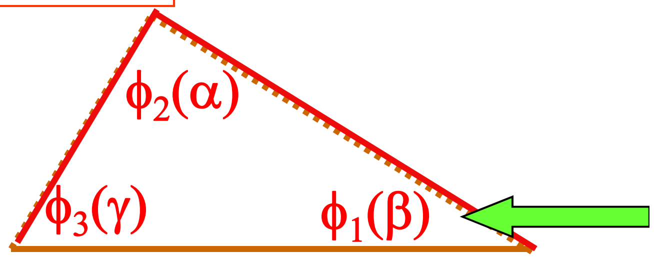


Decay rate asymmetry

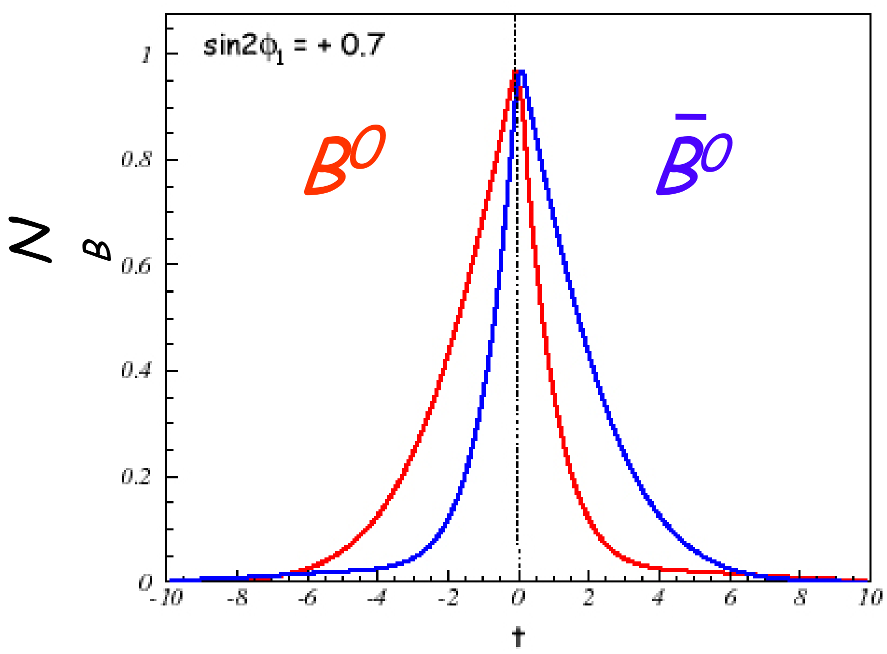
$$a_{f_{CP}} = -\mathrm{Im}(\lambda)\sin(\Delta m t)$$

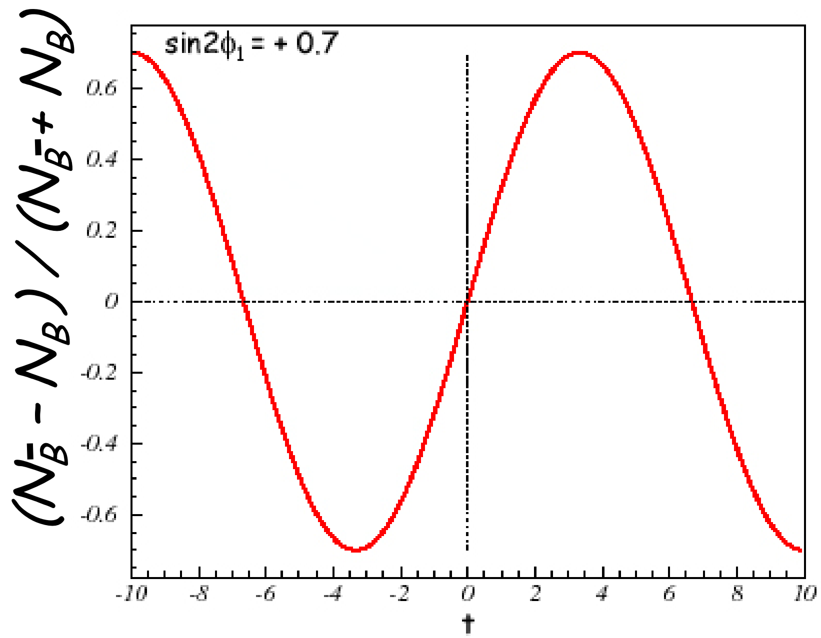
If $|\lambda| = 1$

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



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

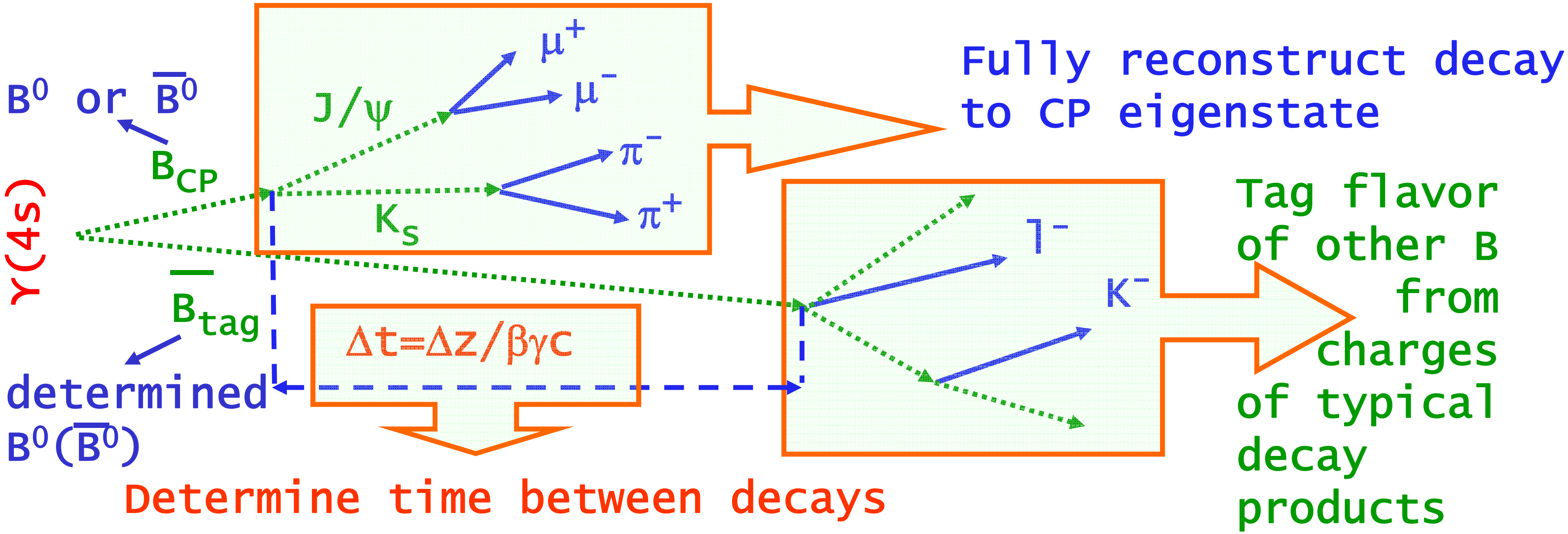




$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

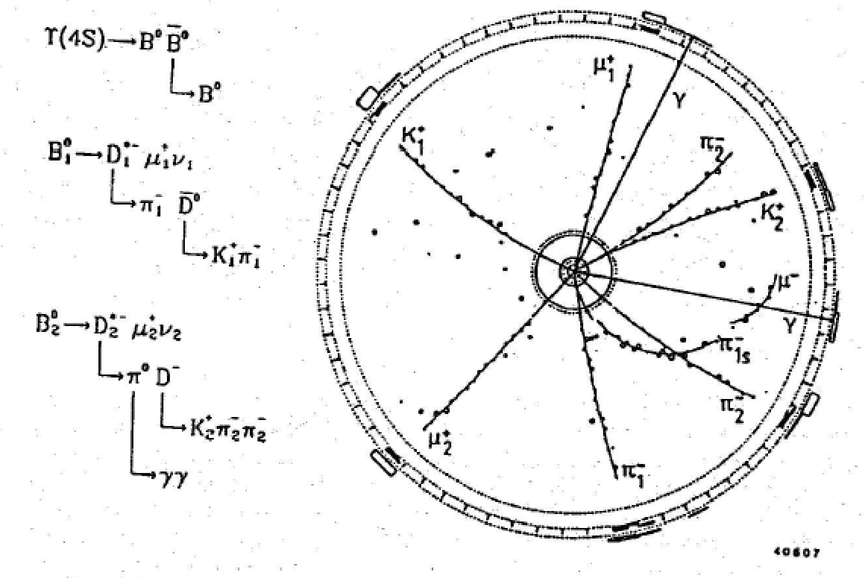
$\xi_f = \pm 1$ ***for*** $CP = \pm 1$

Principle of measurement



Mixing in the B^0 system

1986: ARGUS discovers BB mixing: B^0 turns into anti-B^0



Reconstructed event with one B→anti-B

Integrated Y(4S) luminosity 1983-87: 103 pb^{-1} ~110,000 B pairs

(=1/7000 of the Belle data sample...)

Large mixing in the B^0 system →

→ top is very heavy

→ CP violation effects could be large in B decays

KM scheme predicted - among others – that CP violation in B→J/ψ K_S decays is related to the probability for the b→u transition!

How big is a nano-beam ?

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