Flavour Physics in Last Decade: Belle & BaBar

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Outline

- CP-violation (CPV) and the CKM model
- The B factories
- The angles of the UT (hadronic B decays)
  - β/φ_1
  - α/φ_2
  - γ/φ_3
- The sides (semileptonic/leptonic) B decays
- Charm/Spectroscopy
- Future

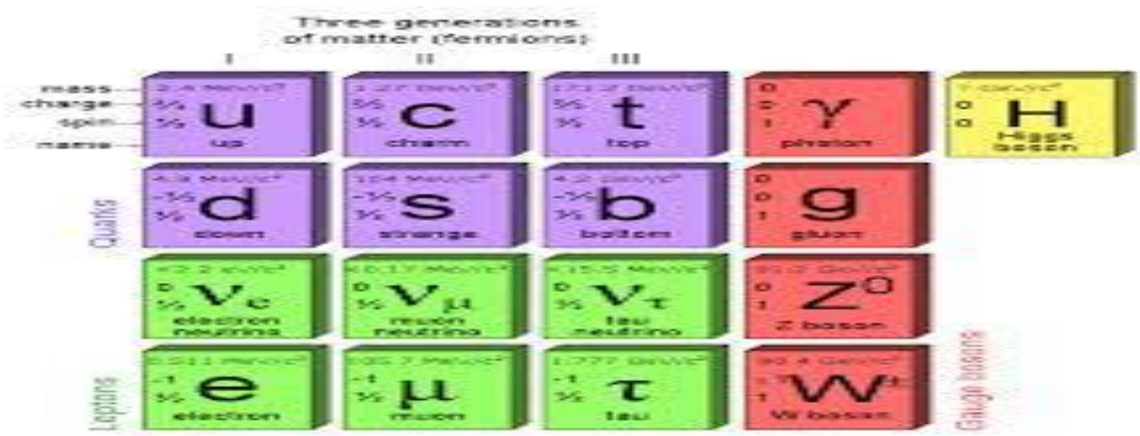
$B \rightarrow$ charmonium K^0

$B \rightarrow \pi K$ / $\pi\pi$

$B \rightarrow$ (D or D) K

Standard Model

- **As of now, most fundamental constituents of matter are quarks and leptons**
- **3 generations of quarks, 3 generations of leptons.**



Despite its tremendous success recognized by several Nobel prizes still many questions remain unanswered!:

– eg. Baryon asymmetry in the universe (CP violation)

– no dark matter candidate

– gravity not part of SM

Symmetries

Nature and its Law: ~ Symmetry = Beauty

P, C, T : most Fundamental Symmetry

P : Parity = Space inversion
C : Charge conjugate (Particle $\leftrightarrow$ Anti-particle)
[Lagrangian $\rightarrow$ Hermitian conjugate]
T : Time reversal

CPT Theorem
Lorentz invariant local quantum field theory $\rightarrow$ CPT symmetry

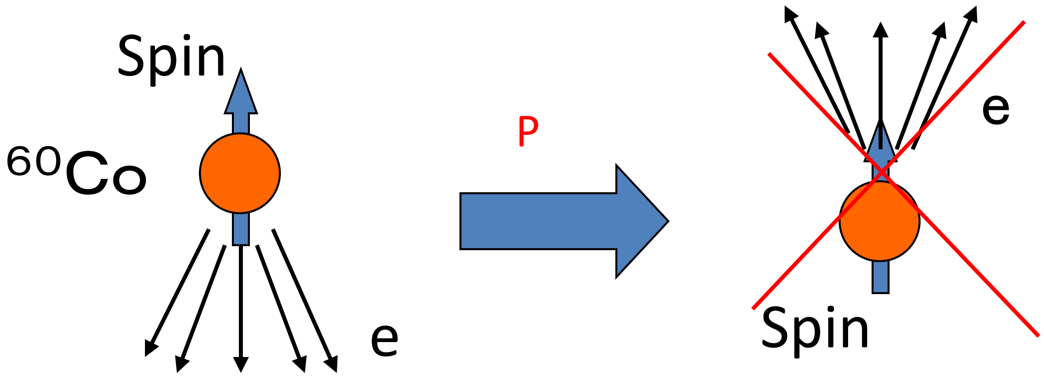
⇨ Particle $\leftrightarrow$ Anti-particle: Mass and Lifetime are identical

P& C Violation

P Violation

1956: Lee-Yang predict P violation [PR 104, 254]

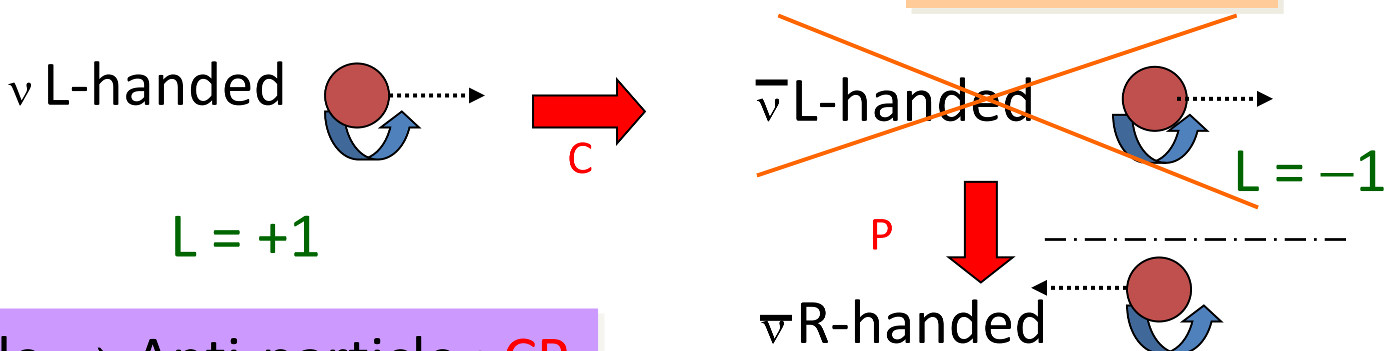
1957: discovered by C.S.Wu in ^{60}Co β-decay [PR 105, 1413]



Weak Interaction
V−A

C violation

Simple Illustration



Physical Particle → Anti-particle : CP

CP Violation

CPV: difference in behavior of particle and anti-particle

1964: discovered in K^0 decay (J.Cronin, V.Fitch et. al.)

[PRL 13, 138]

Observation of $K_L \to \pi^+\pi^-$ ⟹ CP Violation

[K^0-$\overline{K^0}$ mixing]

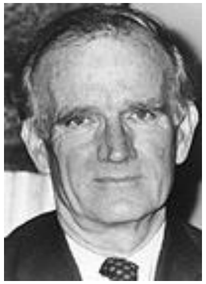
$$\begin{cases} |K_1\rangle = |K^0\rangle + |\overline{K}^0\rangle & [CP=+1] \\ |K_2\rangle = |K^0\rangle - |\overline{K}^0\rangle & [CP=-1] \end{cases}$$

$K_1=K_S$, $K_2=K_L$

If CP conserves

$K_S \to \pi^+\pi^-$ (CP = +1), $K_L \to \pi^+\pi^-\pi^0$ (CP = −1)

Branching fraction = 2.3×10^{-3}



Why CPV is Important ?

Universe: almost “matter” only (no anti-matter)

Big-Bang $\rightarrow$ N(particles) = N(anti-particles)

Sakhalov’s 3 conditions (1967) for Baryogenesis to occur:

1. baryon number violation
2. CP violation
3. Interactions outside the thermal equilibrium

CPV is a key for Existence of Universe & us !

Andrei Sakharov (1921-1989)

The Cabibbo–Kobayashi–Maskawa Quark Mixing Matrix

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

A 3x3 unitary matrix

Described by 4 parameters – allows CP violation

PDG (Chau-Keung) parametrisation: $\theta 12$, $\theta 23$, $\theta 13$, δ

Wolfenstein parametrisation: λ, A, ρ, η

CKM: the matrix and the triangle

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}\left(\lambda^4\right) \quad \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$

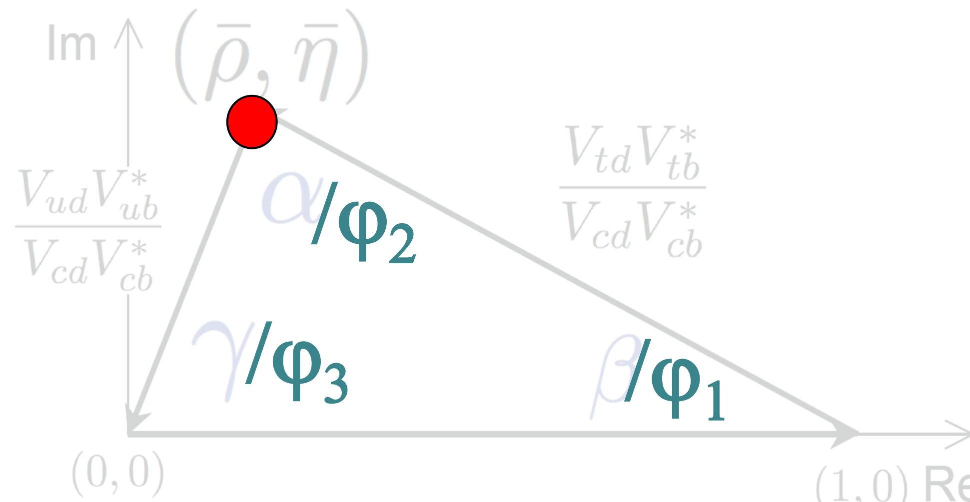
Wolfenstein parameterization

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

$$A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

$$\boxed{\bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}}$$

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



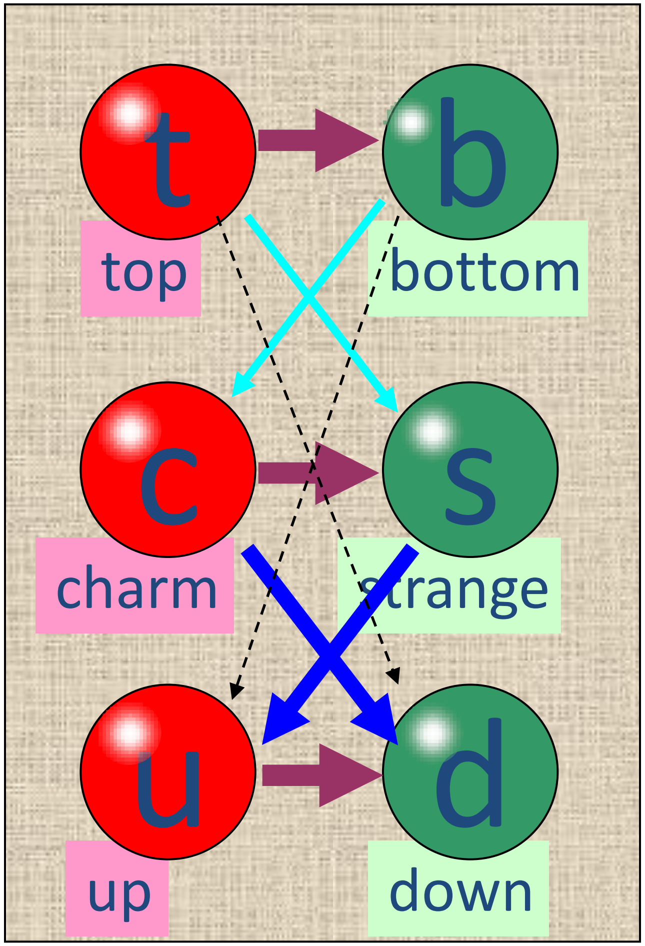
B system: Very Good Place, All angles are of *O*(0.1)!

CPV: Why B ?

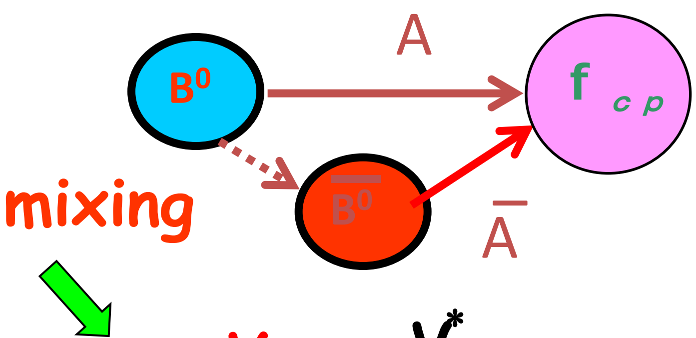
Size of CPV in K: O(10^{-3}) ~ small
not enough information
to confirm KM scheme

Specialty of B
long lifetime (~1.5 ps)
Large B^0-B^0 mixing
Various decay modes

Sanda-Bigi-Carter (1980)
Large CPV in B-system



B^0-$\bar{B}^0$ Mixing & CPV



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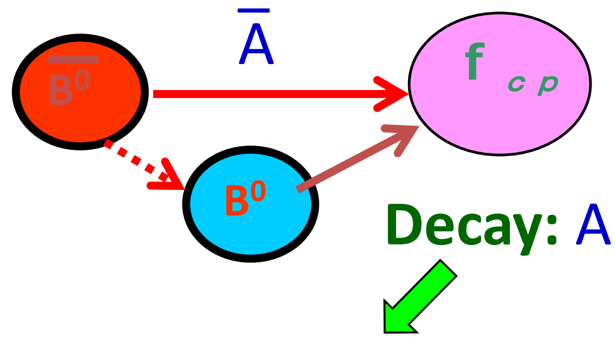
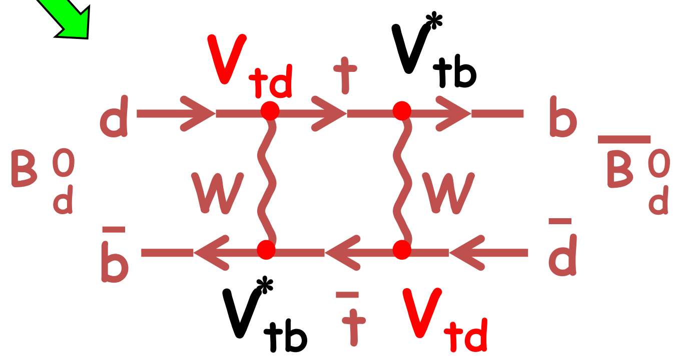
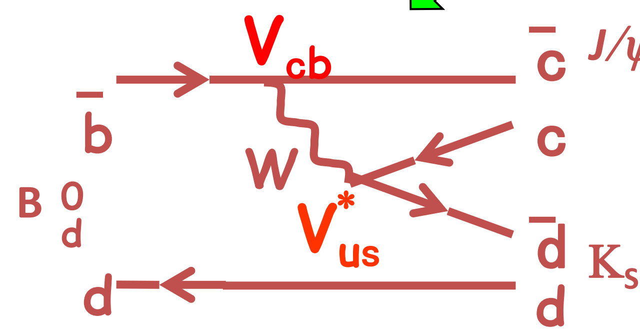
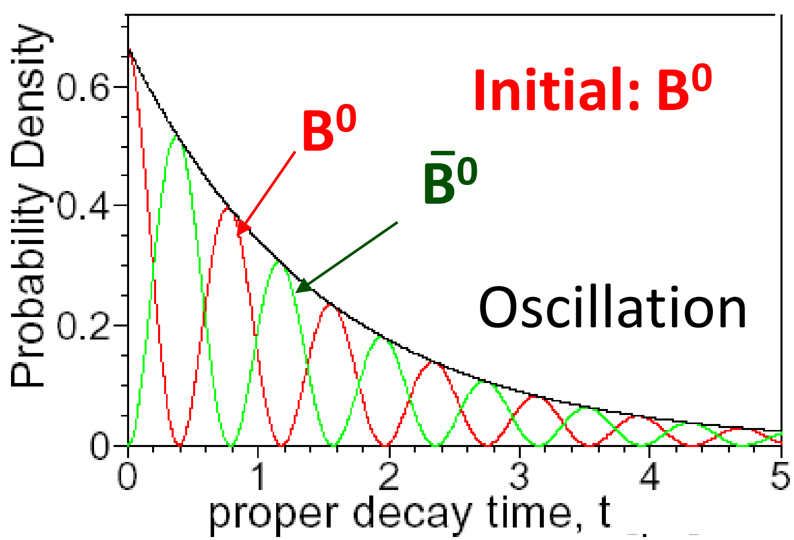


Sanda
Bigi
Carter







Interference
- **Direct decay**
- **Mixing + Decay**

$\Bigg\}$ **Weak Phase difference**

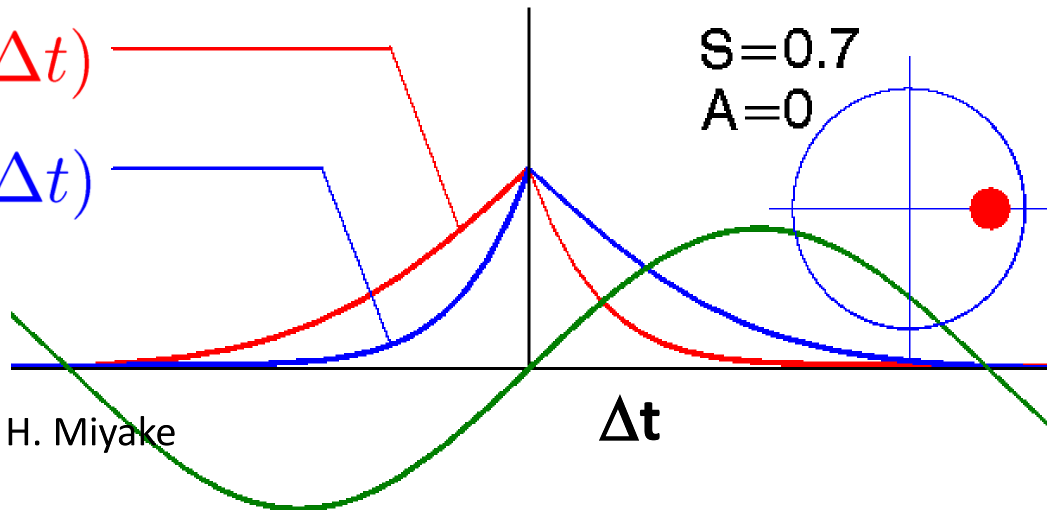
Time dependent CPV

CPV in B: Time-dependent CPV

Sanda
Bigi
Carter

$\Gamma_{B^0}(\Delta t)$

$\Gamma_{\bar{B}^0}(\Delta t)$



made by H. Miyake

$$A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = \mathcal{S}\sin\Delta m\Delta t + \mathcal{A}\cos\Delta m\Delta t$$

$$\mathcal{S} = \frac{2 Im\lambda_{CP}}{1+|\lambda_{CP}|^2}$$

$$\mathcal{A} = \frac{|\lambda_{CP}|^2-1}{|\lambda_{CP}|^2+1}$$

$$\lambda_{CP} = \frac{q}{p}\frac{\bar{A}}{A}$$

mixing decay

$$\left(\frac{q}{p} \cong \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}\right)$$

Mixing-induced CPV

Direct CPV $(\mathcal{A} = -C)$

$A=\bar{A}$: No DCPV
sin-term only

Start of B physics – 1977

VOLUME 39, NUMBER 5 PHYSICAL REVIEW LETTERS 1 AUGUST 1977

Observation of a Dimuon Resonance at 9.5 GeV in 400-GeV Proton-Nucleus Collisions

S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens,[a] H. D. Snyder, and J. K. Yoh
Columbia University, New York, New York 10027

and

J. A. Appel, B. C. Brown, C. N. Brown, W. R. Innes, K. Ueno, and T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

A. S. Ito, H. Jöstlein, D. M. Kaplan, and R. D. Kephart
State University of New York at Stony Brook, Stony Brook, New York 11974

(Received 1 July 1977)

Accepted without review at the request of Edwin L. Goldwasser under policy announced 26 April 1976

Dimuon production is studied in 400-GeV proton-nucleus collisions. A strong enhancement is observed at 9.5 GeV mass in a sample of 9000 dimuon events with a mass $m_{\mu^+\mu^-} > 5$ GeV.

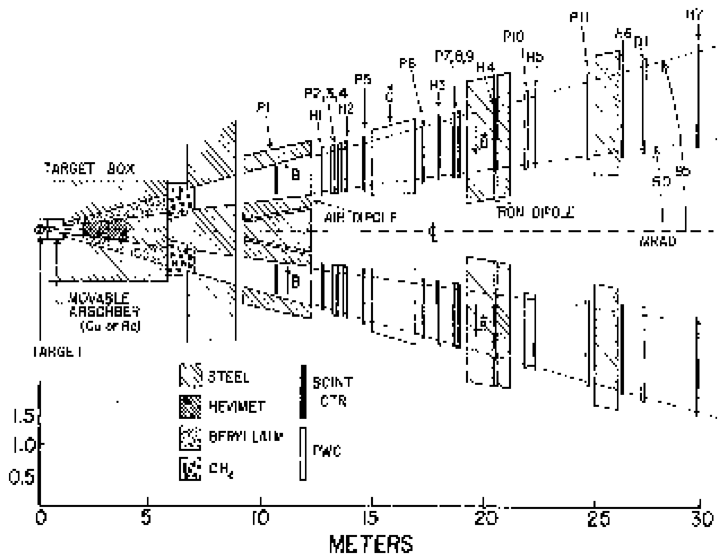
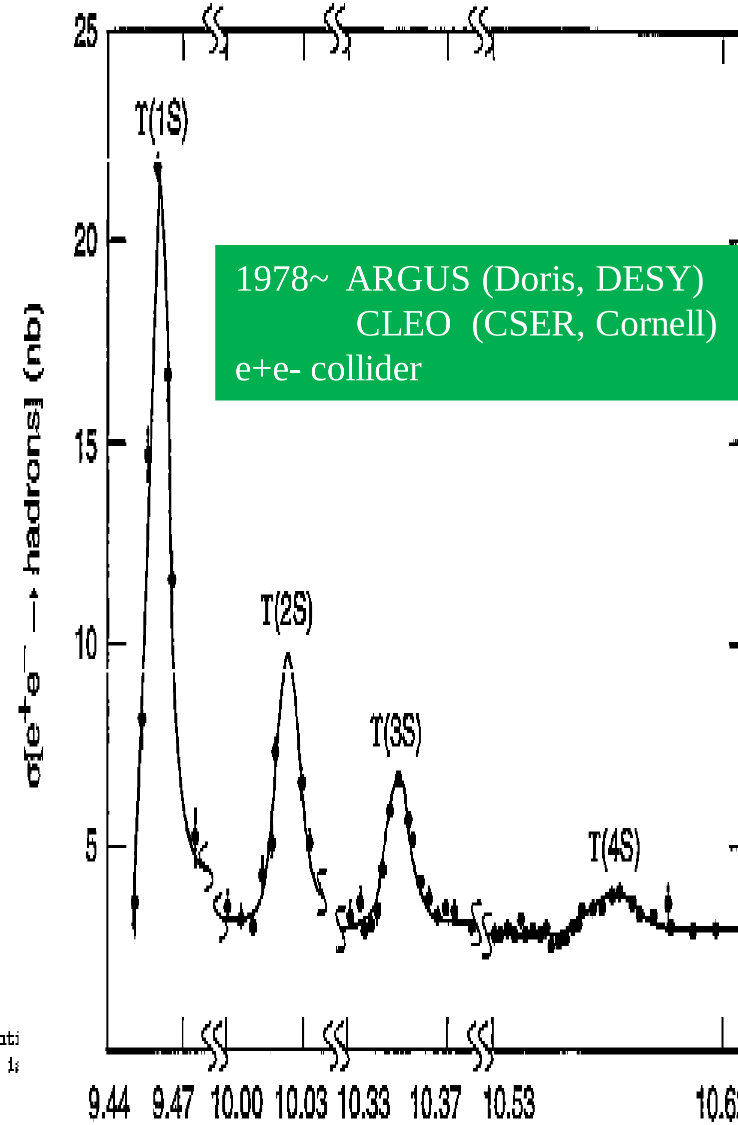
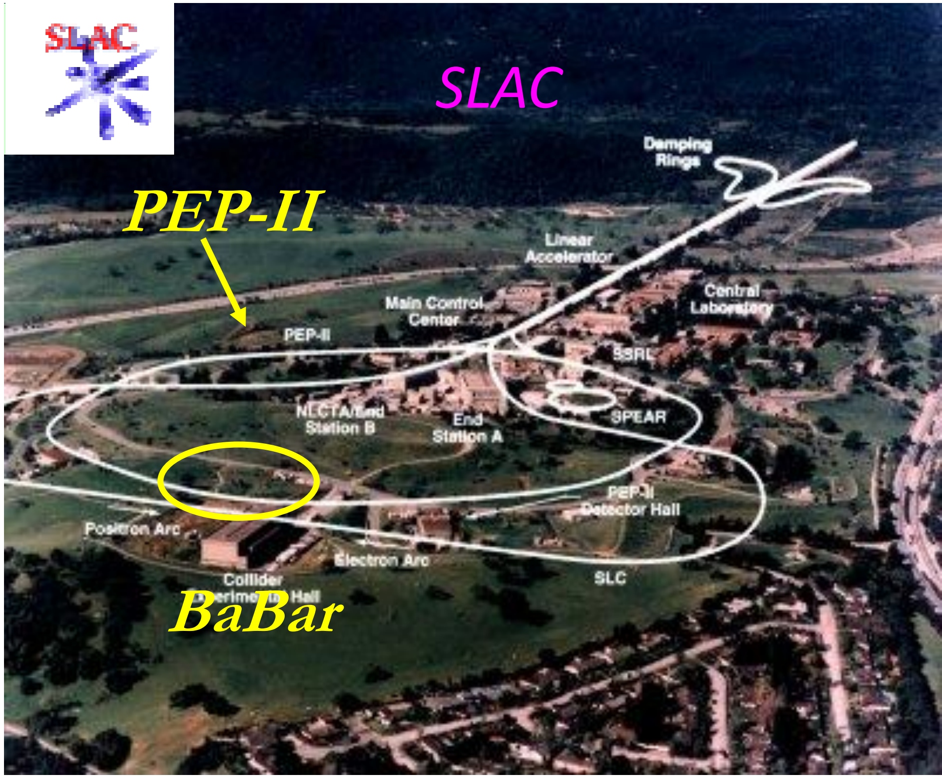


FIG. 1. Plan view of the apparatus. Each spectrometer arm includes eleven PWC's P1–P11, seven scinti counter hodoscopes H1–H7, a drift chamber D1 and a gas-filled threshold Čerenkov counter Č. Each arm is down symmetric and hence accepts both positive and negative muons.



1978~ ARGUS (Doris, DESY)
CLEO (CSER, Cornell)
e+e- collider

Asymmetric B Factories



8 GeV e^- x 3.5 GeV e^+

$\pm$11mrad crossing

KEKB (Japan)

$\beta\gamma$=0.425

9 GeV e^- x 3.1 GeV e^+

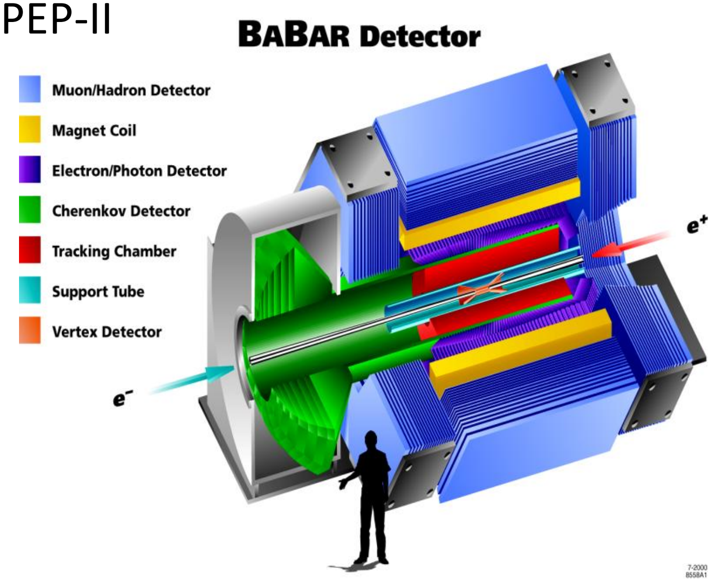
Head-on collision

PEP-II (USA)

$\beta\gamma$=0.56

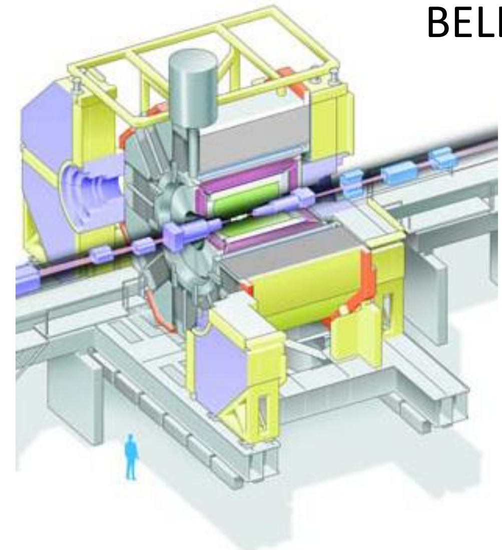
B factories

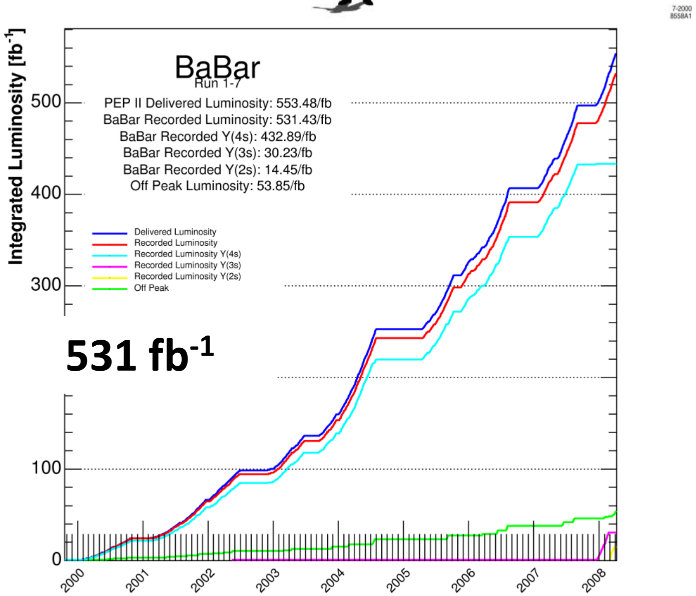
SLAC PEP-II

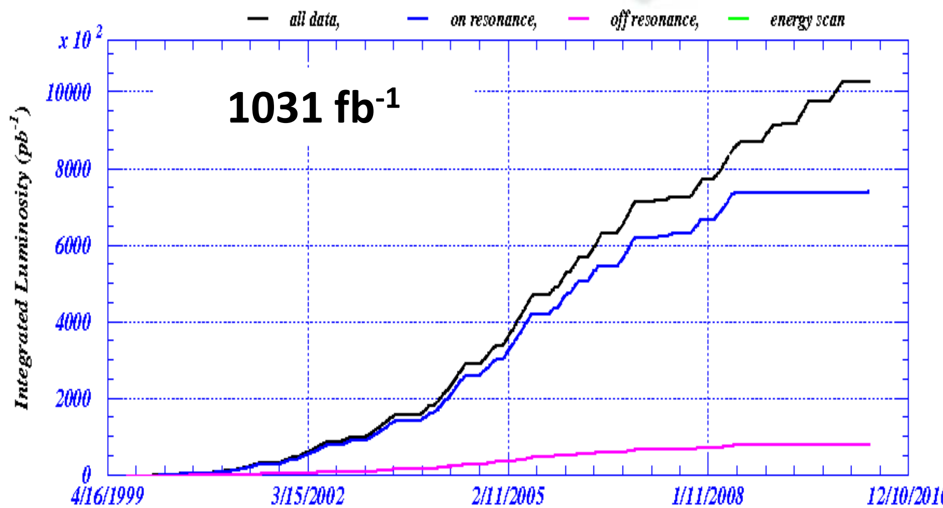


KEK-B

BELLE

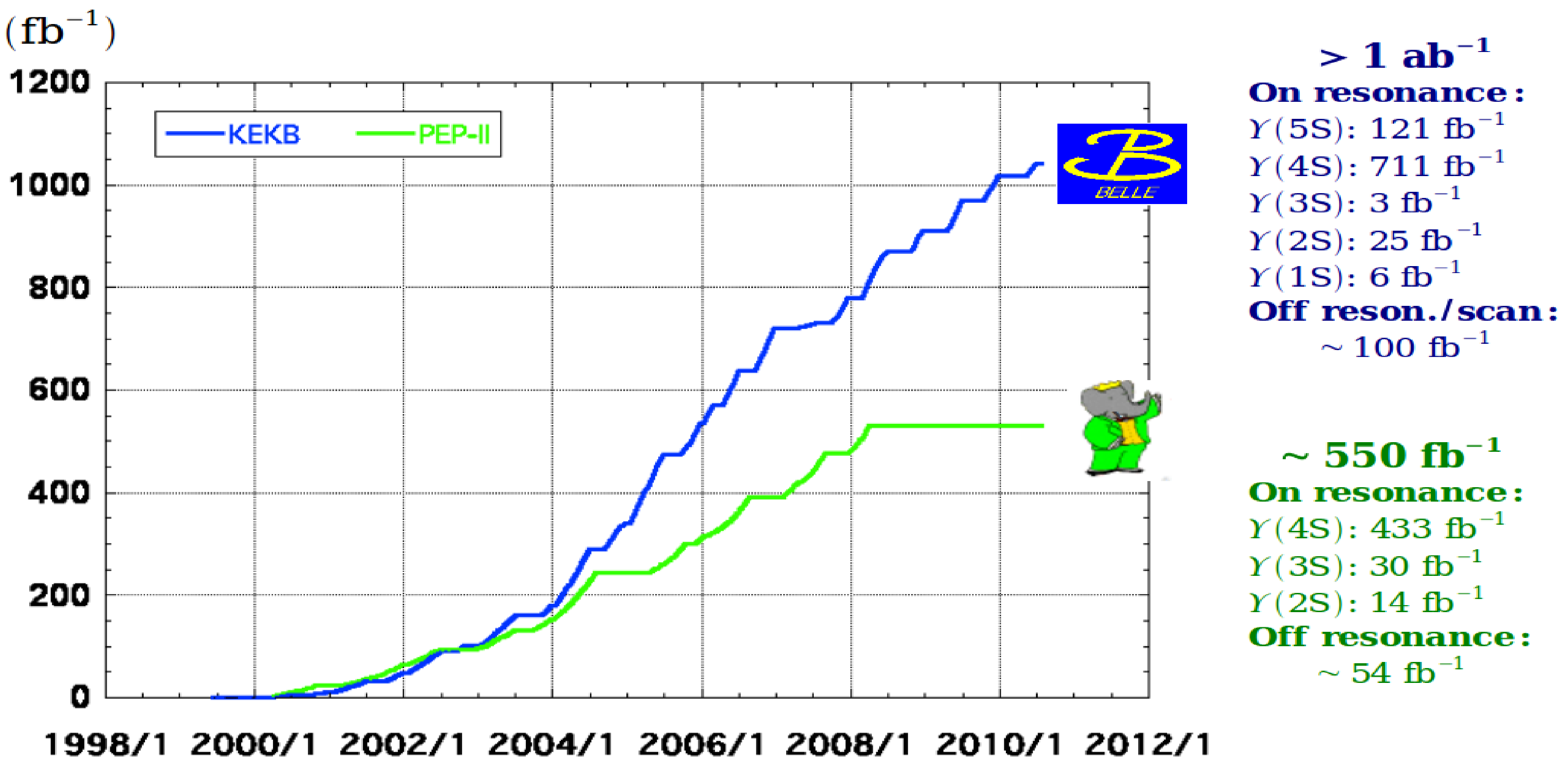






Integrated Luminosity

Integrated luminosity of B factories



In total, more than 1G BB pairs are recorded at B-factories and used to measure angles.

Experiment and Its Goal

B EL LE

BELLE

B (beauty) Meson *Electron (e^-)* *Positron (e^+)*

Goals:

- *Discovery of CP–Violation in B Decays (2001 Summer)*
- *Precise Test of the Standard Model*
- *Search/Evidence for New Physics*

Now

The *Belle* Collaboration

BINP
Bonn U.
Charles U.
Chiba U.
U. of Cincinnati
Fu-Jen C.U.
Giessen U.
Gyeongsang Nat'l U.
Goethingen
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow
IHEP, Vienna

Indiana U.
ITEP
Kanagawa U.
KEK
Karlsruhe U.
KISTI
Korea U.
Krakow Inst. of Nucl. Phys.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
Luther
U. of Melbourne
MPI

Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Osaka RCNP
Osaka City U.
Panjab U.
Peking U.
PNNL
Riken
Saga U.
USTC
Seoul National U.

Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
Torino
Wayne S.U.
VPI
Yonsei U.

15 countries, 64 institutes, ~400 collaborators

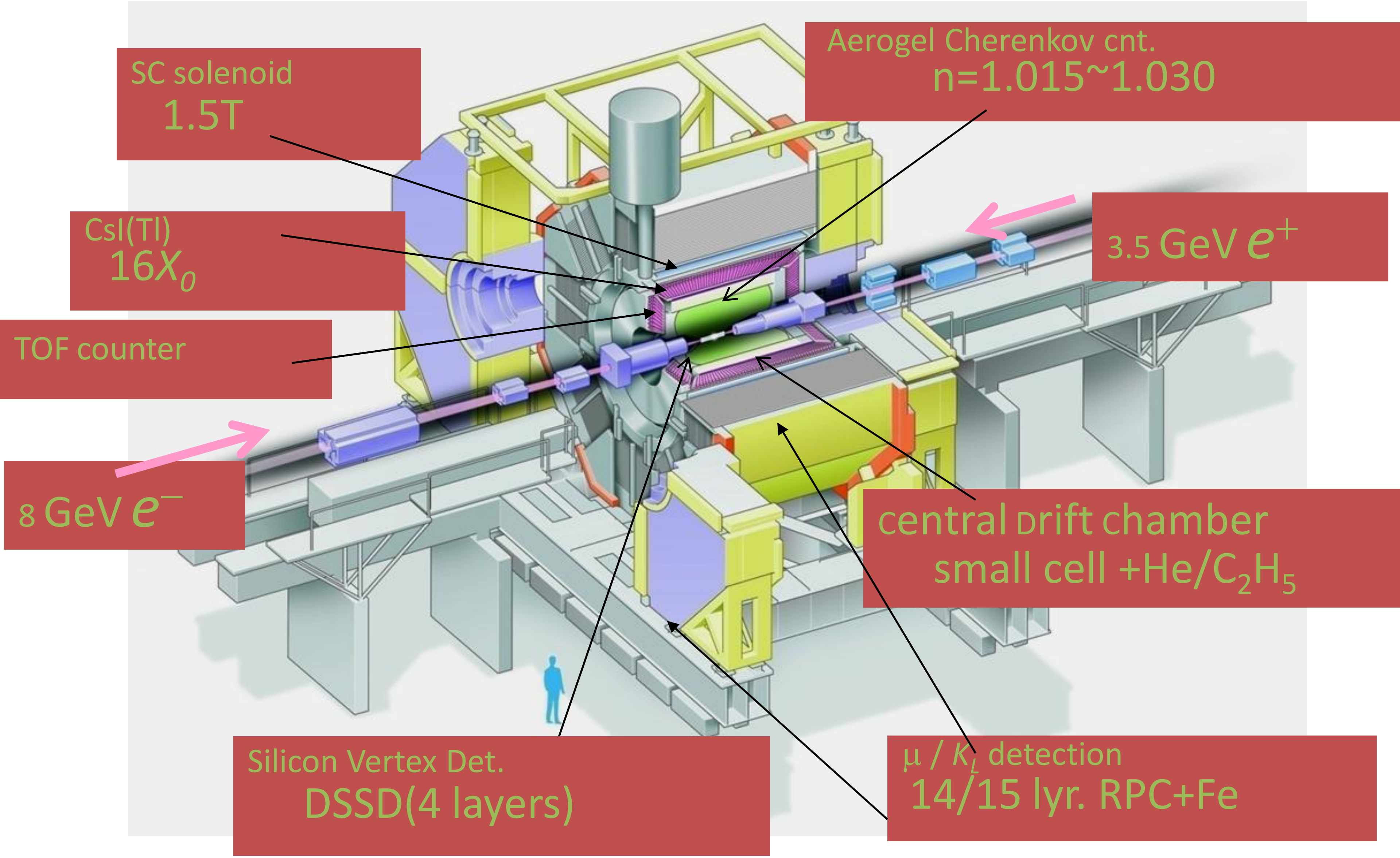
As of Dec., 2013

Participants Indian Institutes

- Indian Institute of Technology, Guwahati
- Indian Institute of Technology, Bubneshwar
- Indian Institute of Technology, Madras
- Indian Institute of Mathematical Sciences, Chennai
- Panjab University, Chandigarh, Union Territory
- Punjab Agricultural University, Ludhiana
- Tata Institute of Fundamental Research, Mumbai

Myself participating in this collaboration since 2004.

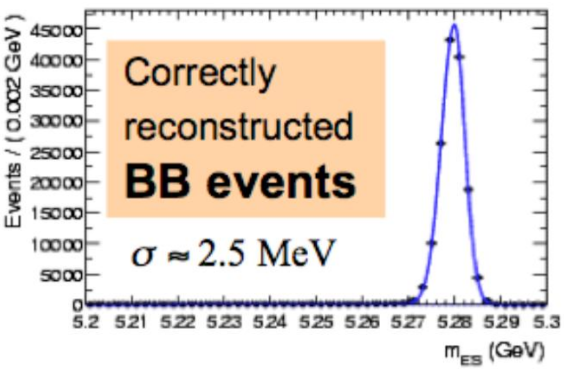
Belle Detector

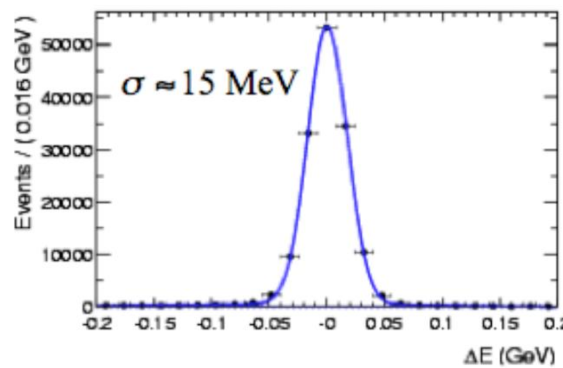


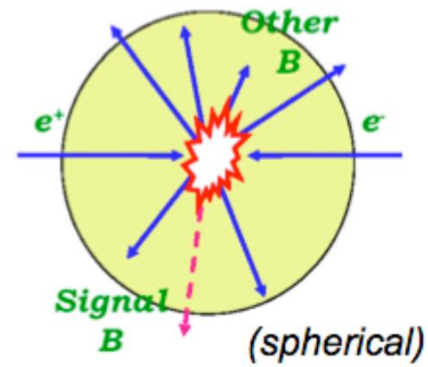
B meson reconstruction

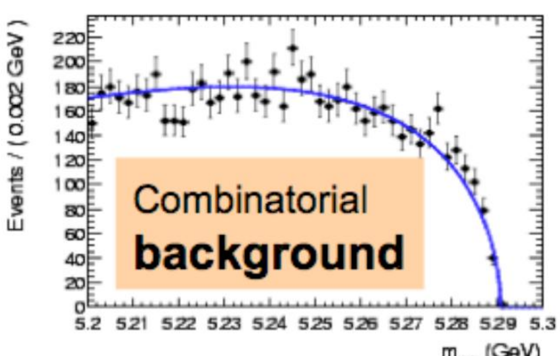
Exploit kinematics of $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ for signal selection

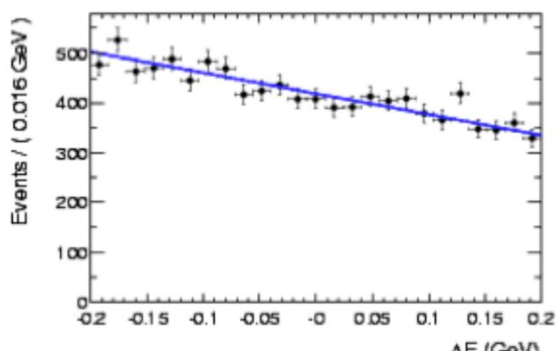
Beam-energy substituted mass	*Energy difference*	*Event topology*
$m_{ES} = \sqrt{E_{beam}^{*\,2} - p_B^{*\,2}}$	$\Delta E = E_B^* - E_{beam}^*$	*(multivariate methods)*

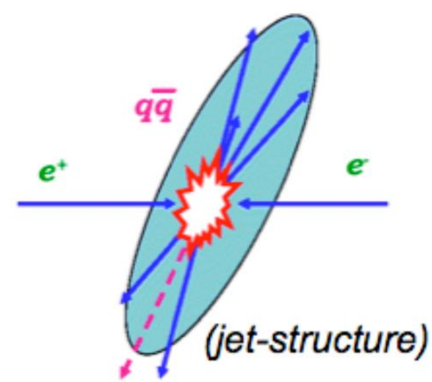








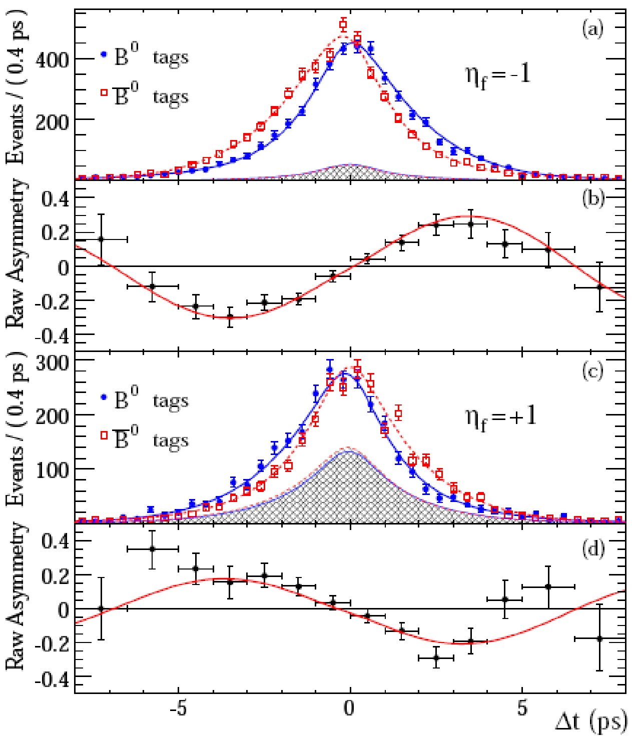




Measurement of sin(2φ1)

Sensitivity to CP violation between B^0 decays to J/ψ K^0 (GOLDEN MODE) with and without mixing

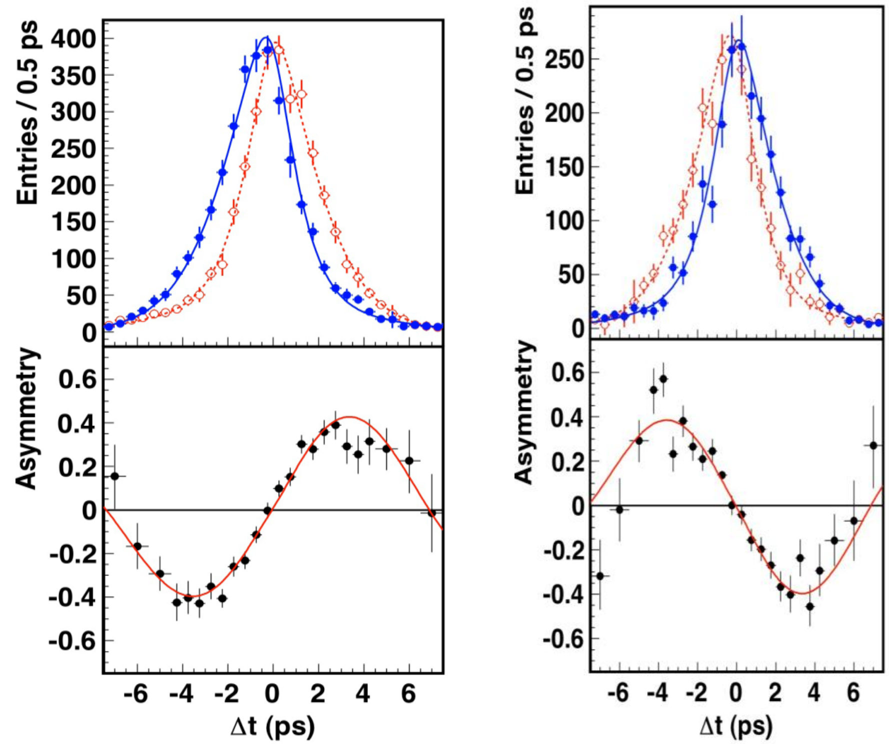
sin(2β) = 0.687 ±0.028 ± 0.012



C=0.016 ± 0.023 ± 0.018

PRD 79 (2009) 072009

$\sin 2\phi_1$=0.668±0.023±0.012

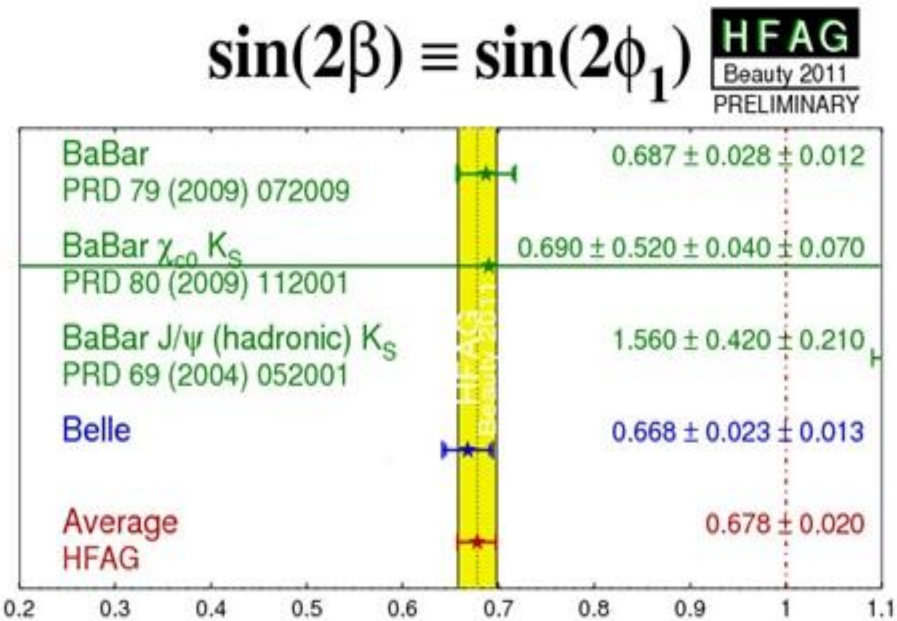


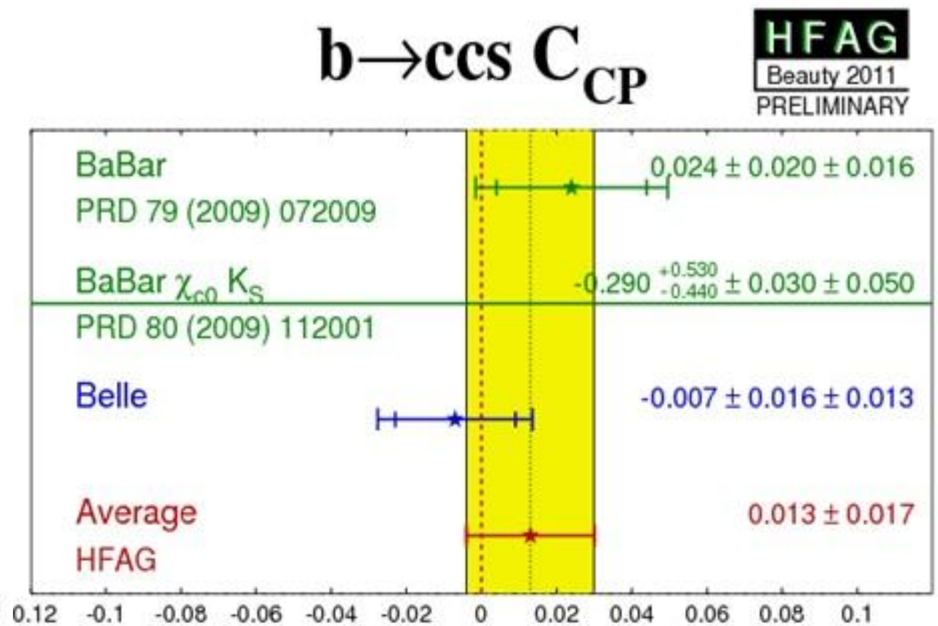
$-C_{fCP} = A_{fCP}$= 0.007±0.016±0.012

PRL 108,171802 (2012)

sin2ϕ1(=sin2β) at Belle (772M BB)

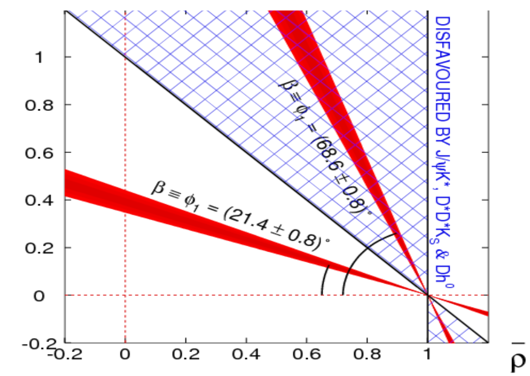
The angle β/ϕ (b→ccs)



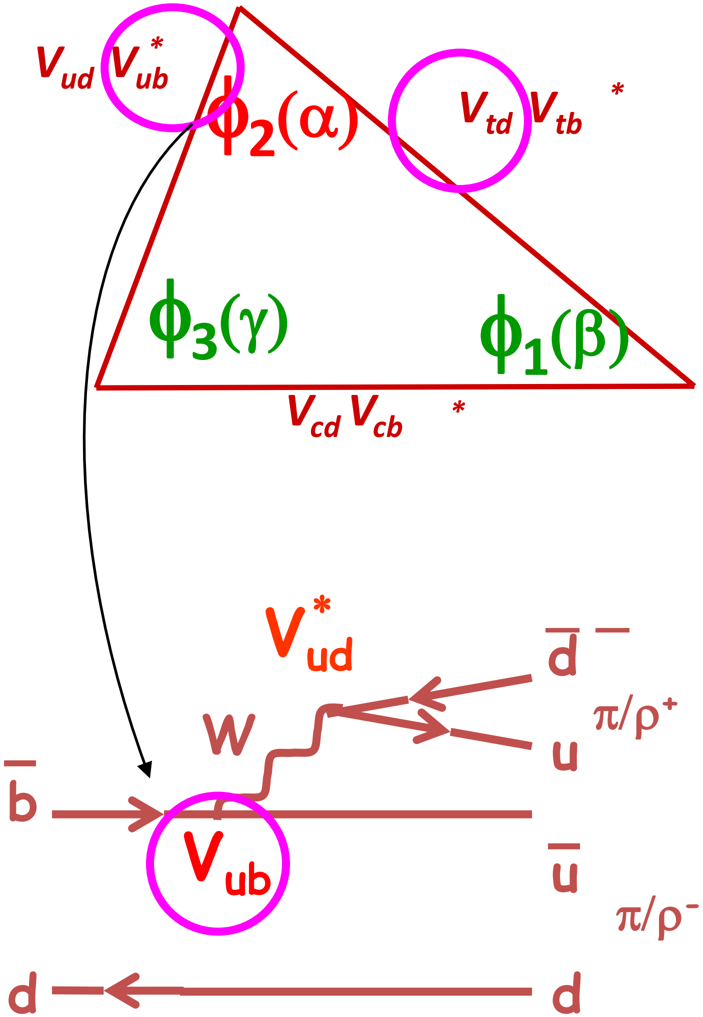


In SM, expect, S=ηsin2β, C=0

sin2β= 0.678 ± 0.020
β=(21.4 0.8) ⁰



ϕ_2 Measurement



Tree

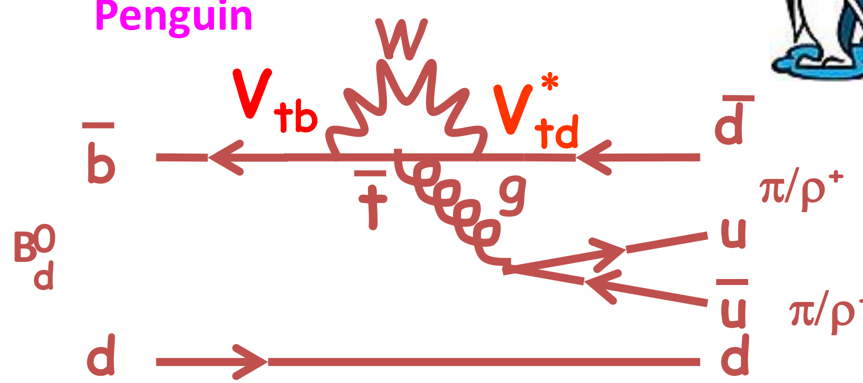
Decay Diagram (Tree)

$S \neq \xi \sin\phi_2$

TDCP more complex because of the Penguin pollution.
Solvable in 2-body ($\pi\pi$) or quasi-2-body ($\rho\rho$) using isospin (Gronau-London [GL] method)
Dalitz analyses of the ($\rho\pi$) channels also sensitive

If tree only, S_f is directly connected to sin2φ2 and A_f = 0.
Interference with b→ d penguin can be solved by isospin analysis.

Penguin

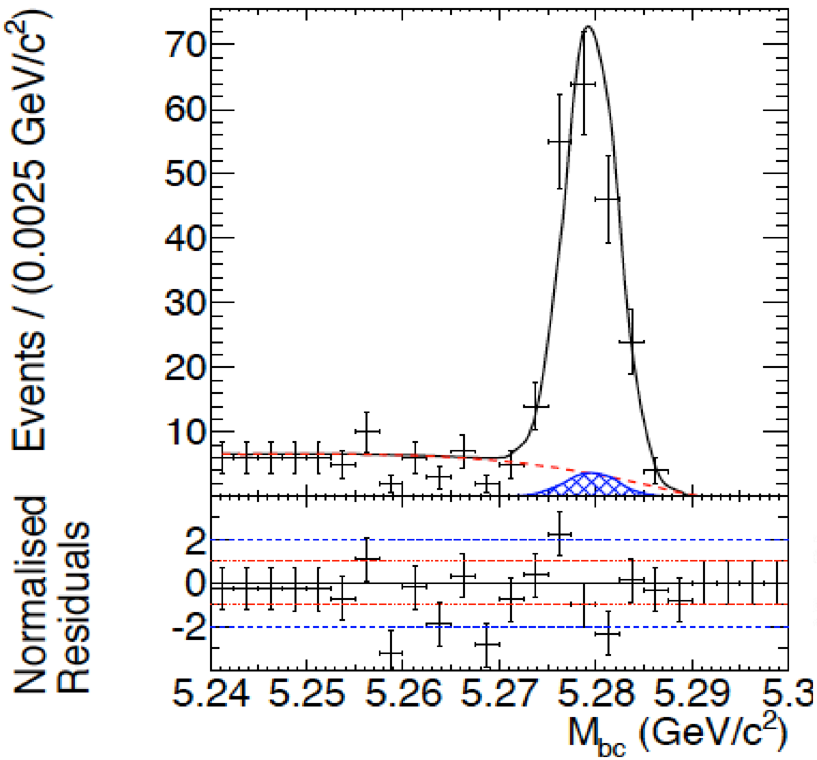


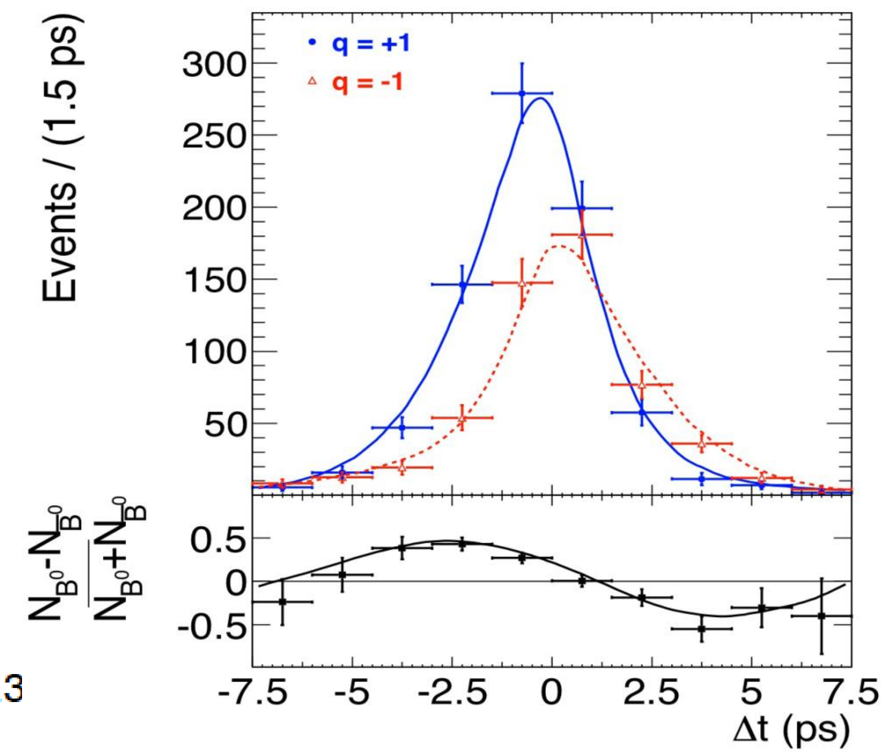
Decay Diagram (Penguin)

$B^0 \rightarrow \pi^+\pi^-$ CPV at Belle (772M BB)

New

ΔE, Mbc, Δt, $L_{K\pi}$, $F_{S/B}$ for $K\pi$, $\pi\pi$, KK simultaneous 6D fit.
$B0 \rightarrow \pi+\pi-$ signal yield : 2886 ± 82 events.

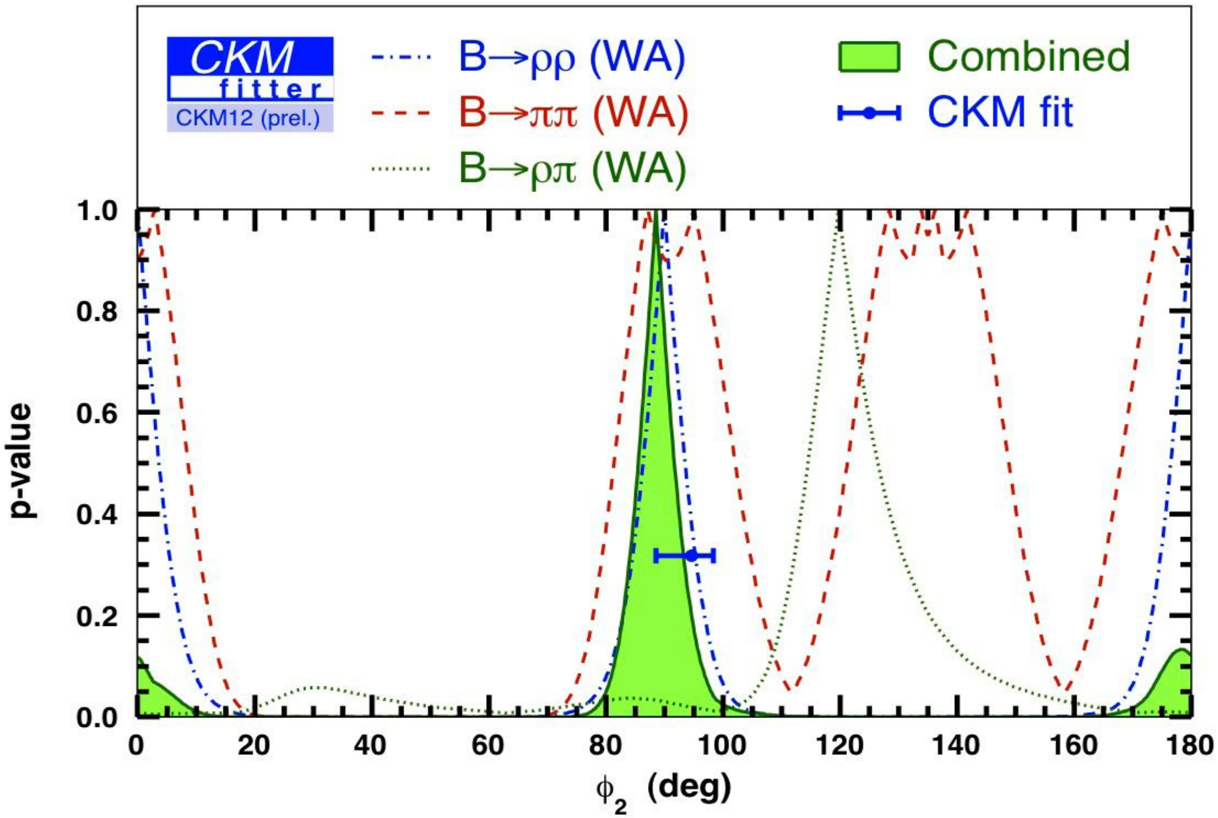




S_{fCP} =-0.636±0.082±0.027

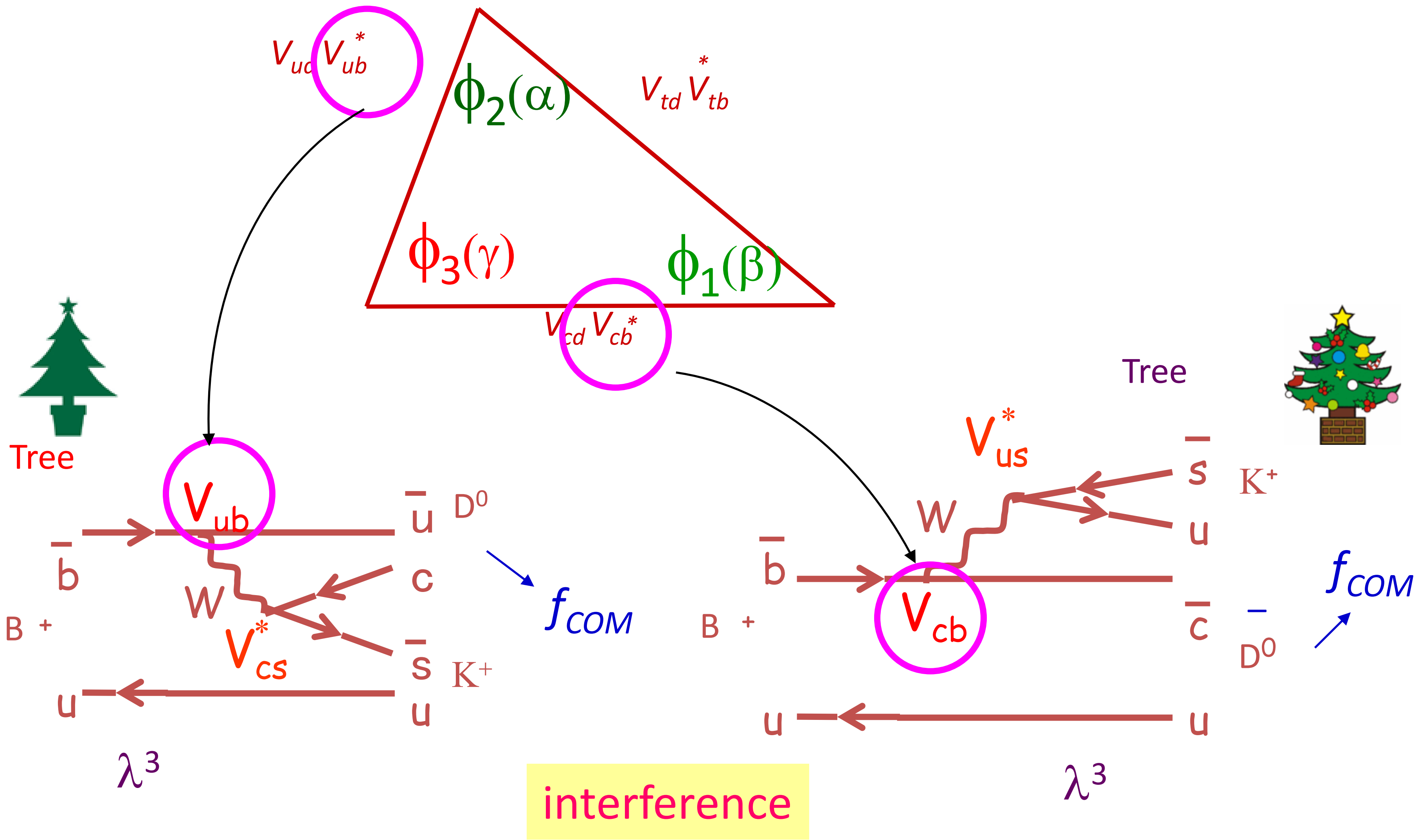
$-C_{fCP} = A_{fCP}$ =+0.328±0.061±0.027

New constraint by ππ/ρρ/ρπ modes



α=ϕ2=(88.5 +4.7/-4.4)°

ϕ_3 measurement



ϕ_3 measurement

- Pure tree processes!
- Large uncertainties because of different amplitudes
- Works for charged (and neutral) B's.
- Different Methods: GLW, ADS, GGSZ

$\phi_3=\gamma$ constraint

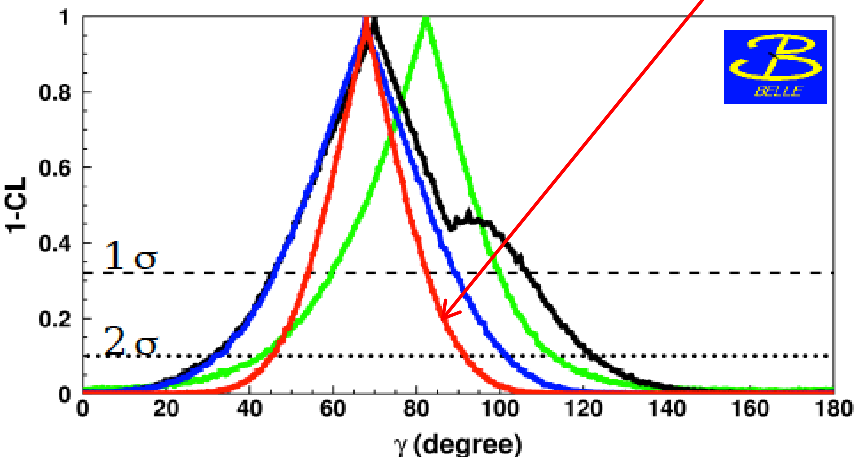
Principle	Method Name and reference
D^0 or $D^{*0} \rightarrow$ CP eigenstate	GLW, PLB253,483(1991), PLB265,172(1991)
Enhance CP asymmetry by suppressed D decay	ADS, PRL78,3357(1997), PRD63,036005(2001)
Dalitz distribution in three-body D decay ($K_S p^+ p^-$, etc)	GGSZ, PRD68,054018(2003), Belle Dalitz Analysis meeting proceedings

Use all available information to get $\phi_3=\gamma$.

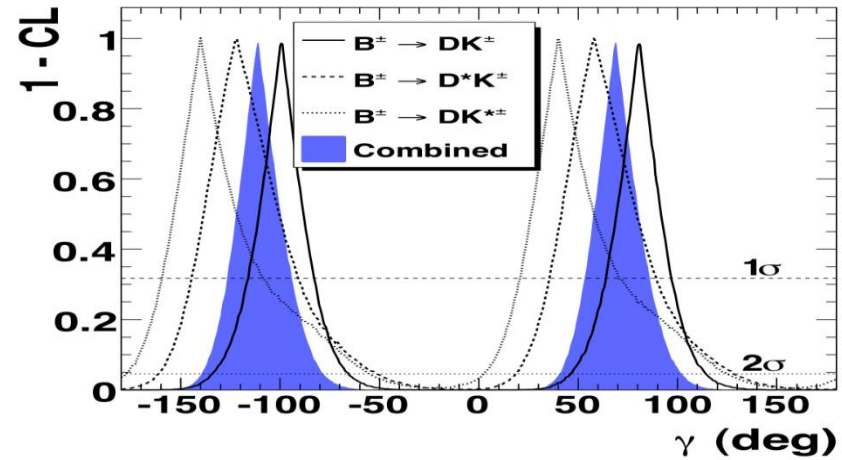
ϕ_3 measurement

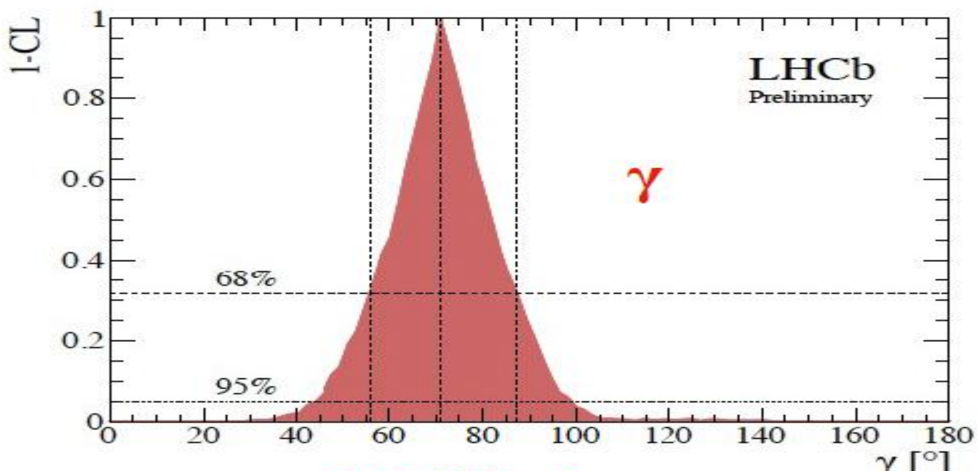
$\phi_3 = (68\ {+15}/{-14})^\circ$

GGSZ+ADS+GLW



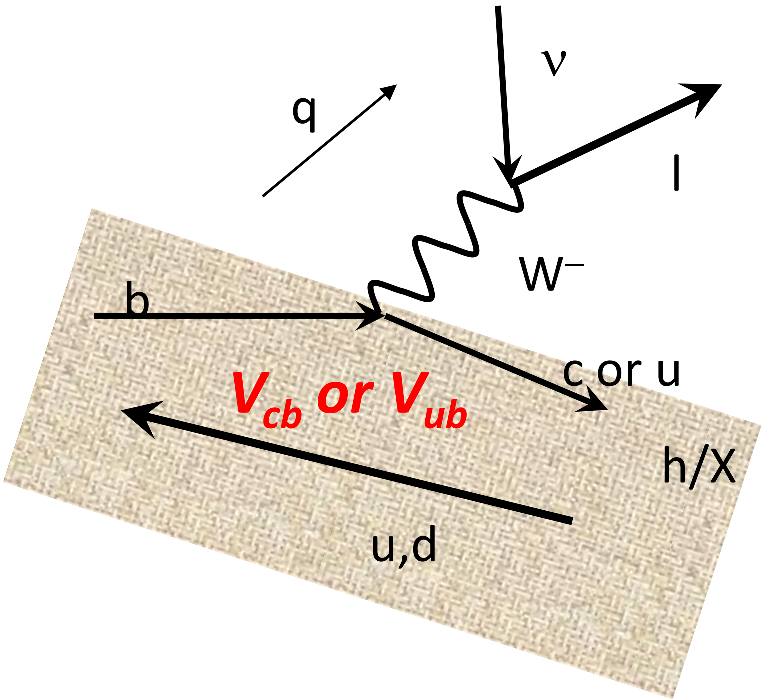
$\phi_3 = \gamma = (69\ {+17}/{-16})^\circ$

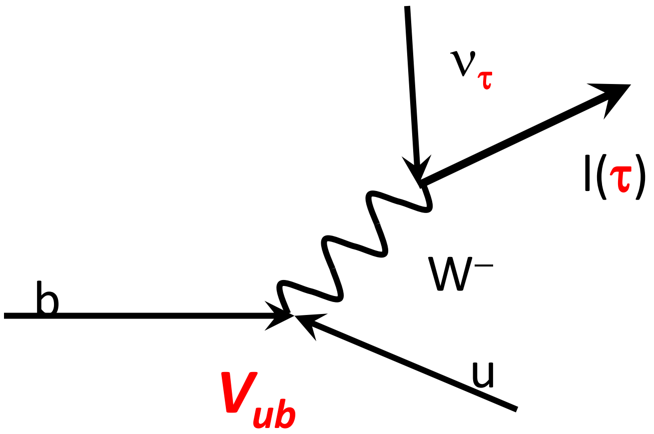




$71.1^{+16.6}_{-15.7}{}^\circ$

The sides of CKM





(Semi)leptonic B decays

- |Vcb| (10^{-3})
  - Exclusive 38.9 ± 1.1
  - Inclusive 41.9 ± 0.7
  - Average 41.0 ± 1.3
    scale factor 2.2
  - in CKMfitter: 40.89 ±0.38 ±0.59
- |Vub| (10^{-3})
  - Exclusive 3.25 ±0.12 ±0.28
  - Inclusive 4.25 ±0.15 ±0.20
  - Average 3.97 ±0.43
    scale factor 2.0
  - In CKMfitter: 3.92 ±0.09 ±0.45

- BR ($B \to \tau\nu_\tau$) (10^{-6})

Exp.	Tag	Measurement	Ref.
BaBar	s.l.	$180 \pm 80 \pm 10$	PRD81:051101,2010
Belle	s.l.	$154^{+38}_{-37}\ ^{+29}_{-31}$	PRD82:071101,2010
BaBar	had.	$179^{+56}_{-49} \pm 26$	arXiv 1008.104
Belle	had.	164 ± 34	PRL97:251802,2006

In CKMfitter: 168 ± 31

Marginal agreement between inclusive and exclusive measurements both for Vub and Vcb (A discrepency of 2σ)

Search for CPV in τ/charm/Spectrosc...

- Charm

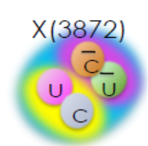
le

QCD is another least understood part of the SM.

We may know the fundamental equation, but do not know how it generates hadrons which is the fundamental element of material.

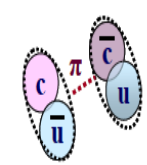
“The absence of exotics is one of the most obvious features of QCD” – R. L. Jaffe, 2005

“The story of pentaquark shows how poorly we understand QCD” – F. Wilczek, 2005

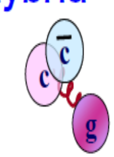


				ISR
		82 +51/-28	$\pi\chi_{c1}$	B decay
X(4160)	4156±29	139 +113/-65	D*D*	Double-charm
Z(4248)+	4248 +185/-45	177 +320/-72	$\pi\chi_{c1}$	B decay
Y(4260)	4264±12	83±22	J/ψππ	ISR
X(4350)	4350 +4.7/-5.1	13 +18/-14	J/ψφ	γγ
Y(4350)	4361±13	74±18	ψ'ππ	ISR
Z(4430)+	4433±5	45 +35/-18	ψ'π	B decay
Y(4660)	4664±12	48±15	ψ'ππ	ISR
Y_b(10890)	10889.6±2.3	54.7 +8.9/-7.6	ππϒ(nS)	e^+e^- annihilation
Z_b(10610)	10608.4±2.0	15.6±2.5	(ϒ(nS) or h_b) π	ϒ(5S) /Y_b decay
Z_b(10650)	10653.2±1.5	14.4±3.2	(ϒ(nS) or h_b) π	ϒ(5S) /Y_b decay

$D^{(*)}D^{(*)}$ Molecule



Hybrid



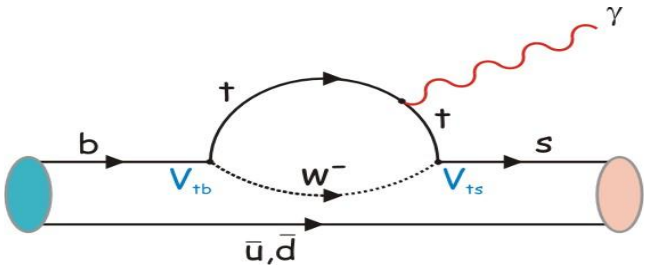
B factories: a success story

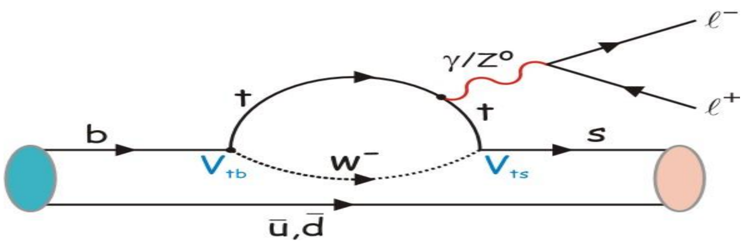
- Measurements of CKM matrix elements and angles of the unitarity triangle ($\phi 1$ at unprecedented precision)
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., B→**τν**, D**τν**) by fully reconstructing the other B meson
- Observation of D mixing, Evidence of CP violation in Charm
- CP violation in b→s transiti… new sources if CPV
- Observation of nev… spectroscopy

What Next!!!

Physics at a SuperKEK B Factory

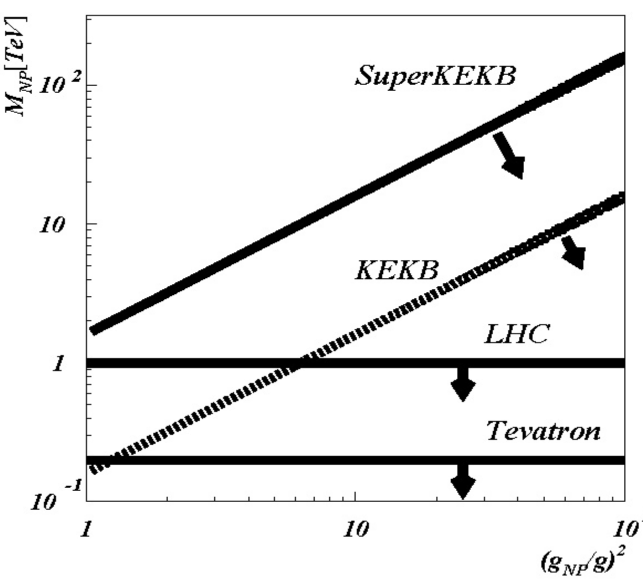
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.





- 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.**
  - **There are many more topics: CPV in charm, new hadrons**
- **Physics motivation is independent of LHC experiment at CERN, Switzerland**.
  - 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.

arxiv:1011.0352



Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

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

Vertical beta function@IP

(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

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	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

- **Nano-beams and a factor of two more beam current** to increase luminosity

Requirements for the Belle II detector

L: 2 x 10^{34} $cm^{-2}s^{-1}$ → 8 x 10^{35} $cm^{-2}s^{-1}$
(Belle) (Belle II)

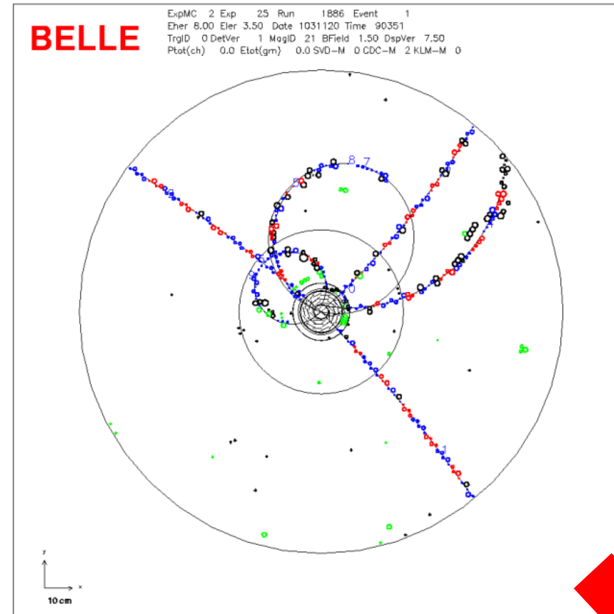
Critical issues at L= 8 x 10^{35}/cm^2/sec

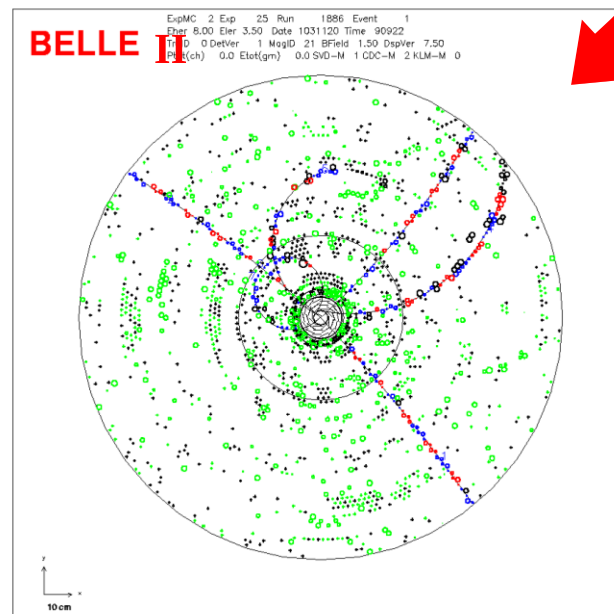
- **Higher background (×20)**
  - radiation damage and occupancy
  - fake hits and pile-up
- **Higher event rate (×10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low *p* μ identification

Possible solution:

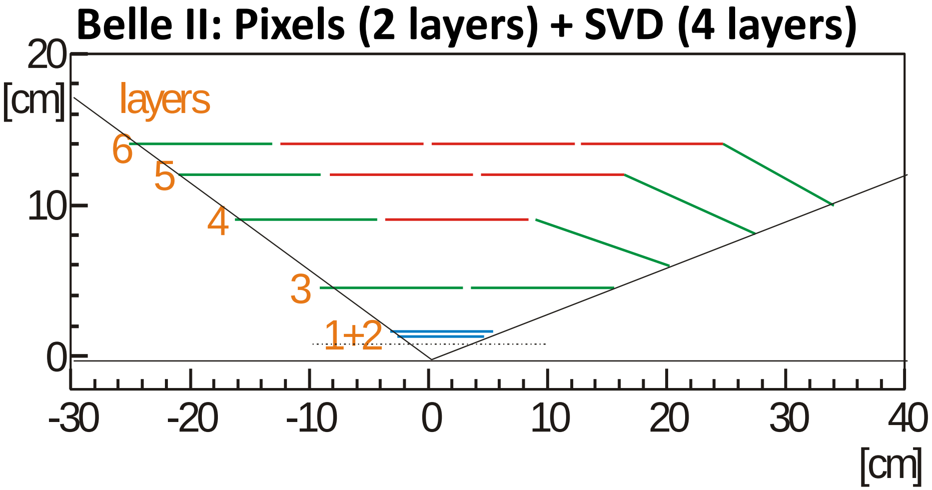
- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter crystals
- Faster readout electronics and computing system.

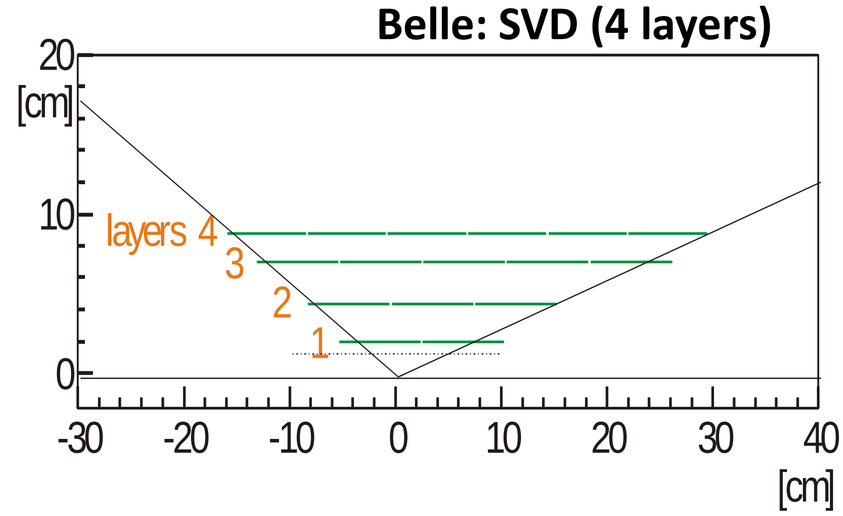
decreased boost γβ → better vertex needed





Vertex Detector Upgrade

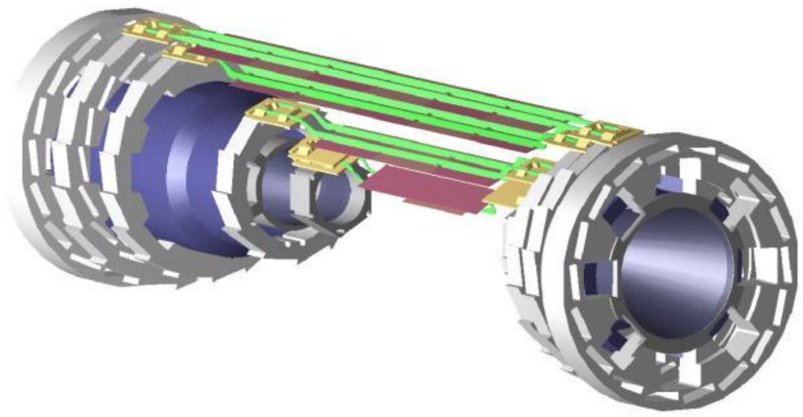




Belle SVD:

- **4 straight layers** of **4" double-sided silicon detectors** (DSSDs)
- Outer radius of r~8.8 cm

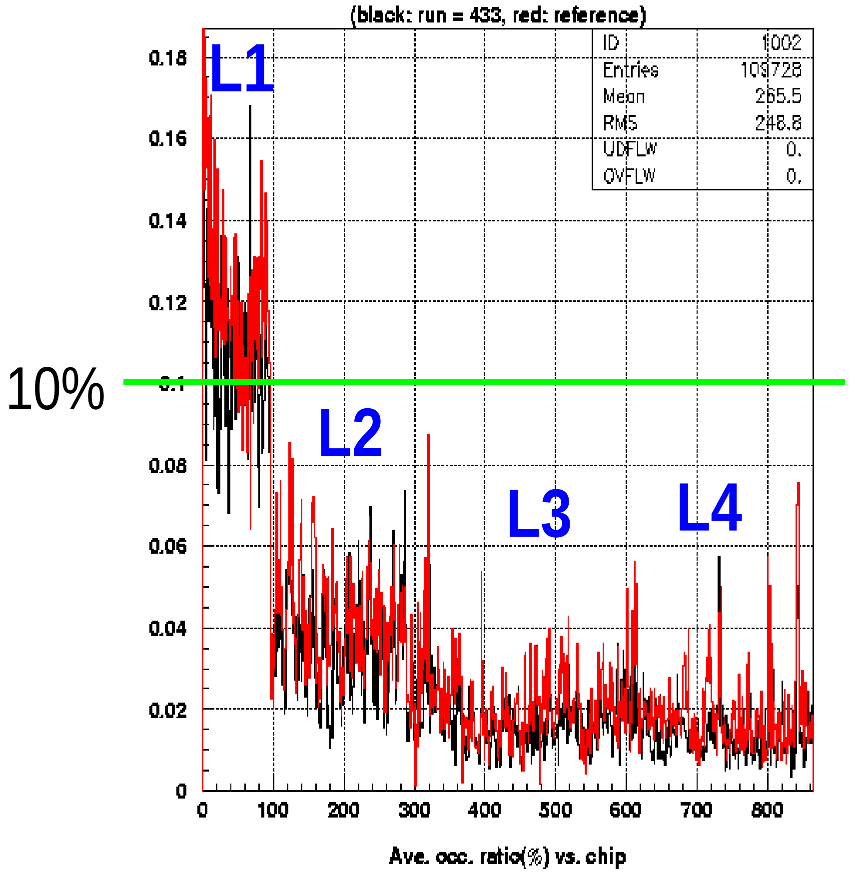
- **Three 4” sensors are daisy- chained** and read out by one hybrid located outside of acceptance region (VA1 chip)



Belle Silicon Vertex Detector (SVD)

- Previous SVD limitations were
  - **occupancy** (currently ~10% in innermost layer)
    $\rightarrow$ need faster shaping
  - **dead time** (currently ~3%)
    $\rightarrow$ need faster readout and pipeline

- Belle II needs detector with
  - high **background tolerance**
  - **pipelined** readout
  - **robust tracking**
  - **low material budget** in active volume



Current SVD is not suitable for Belle II

New Layout for Belle II SVD (2014-)

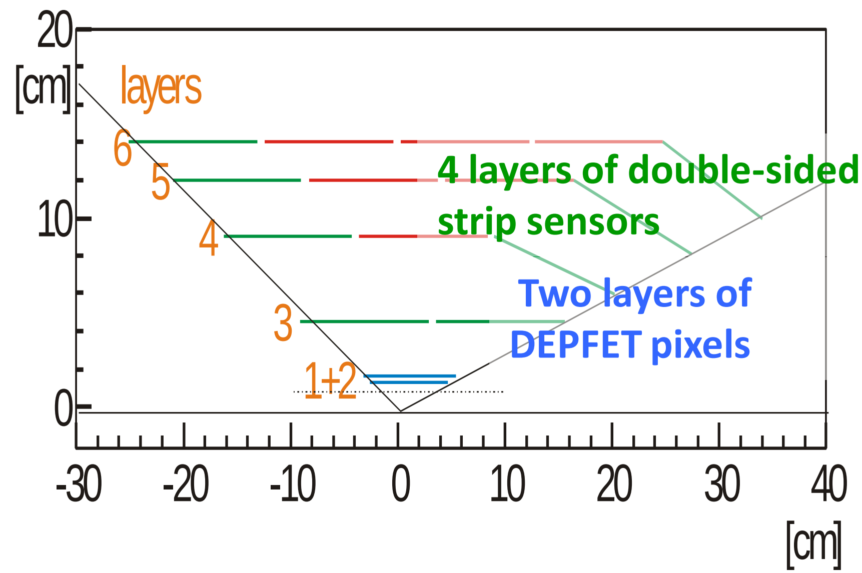
Belle II environment:
- Occupancy : 0.4 hits/μm^2/s
- average particle momentum: ~500 MeV

-Radiation tolerance: > 1Mrad/year

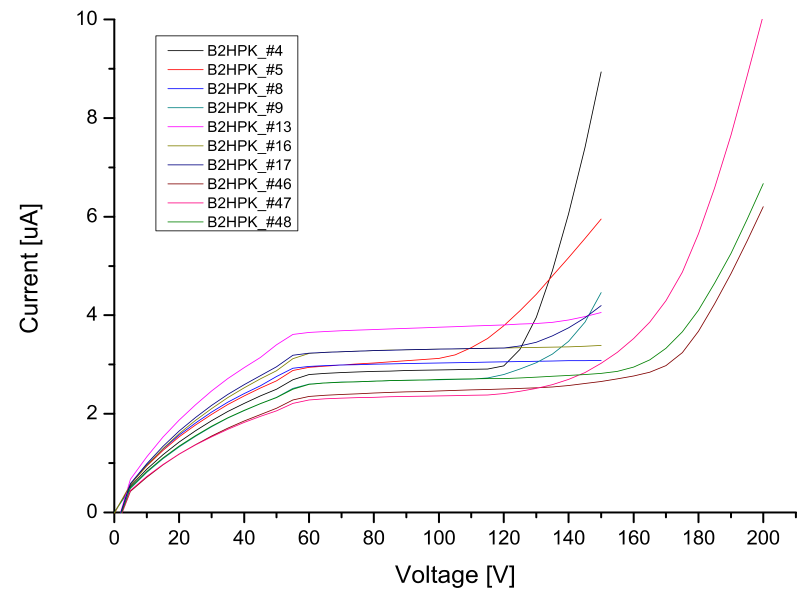
- Acceptance: 17^o-155^o

-- Higher vertex resolution

- -> lower material budget (low scattering)



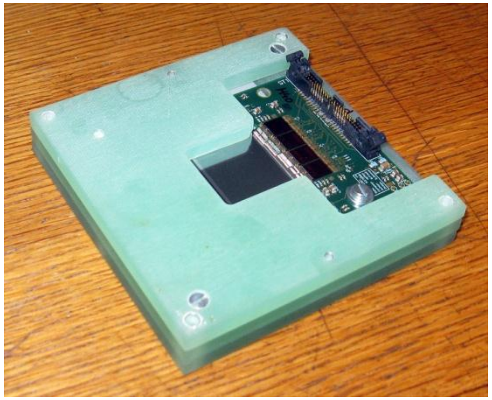
- New double-layer pixel detector using **DEPFET** technology
- Four layers with 6" **double-sided strip detectors at larger radii** and **forward part**

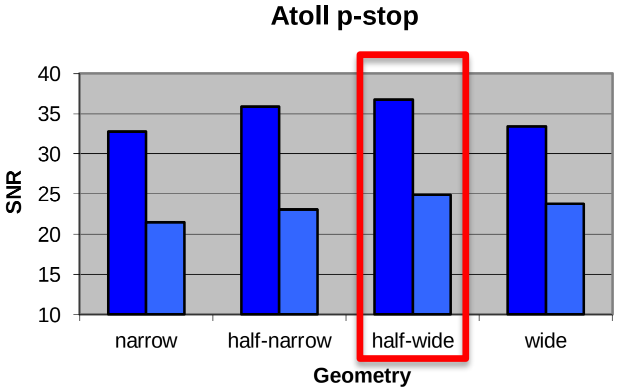


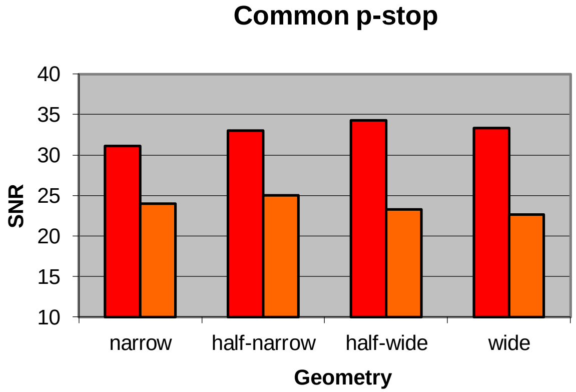
Optimized for precision vertex reconstruction of the decays of short-lived B-mesons

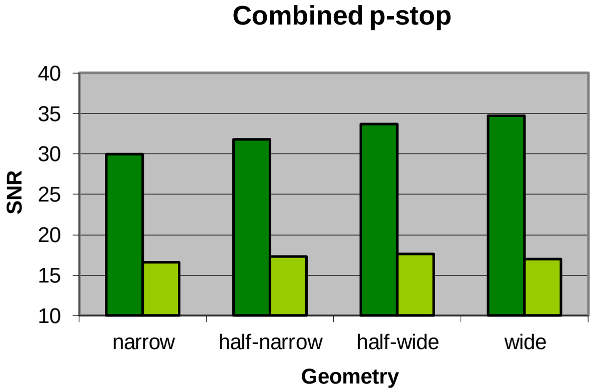
Signal-to-noise-ratios

- Test sensors have been Gamma-irradiated with Co-60
- Tested before and after at CERN beam test (120 GeV hadrons)





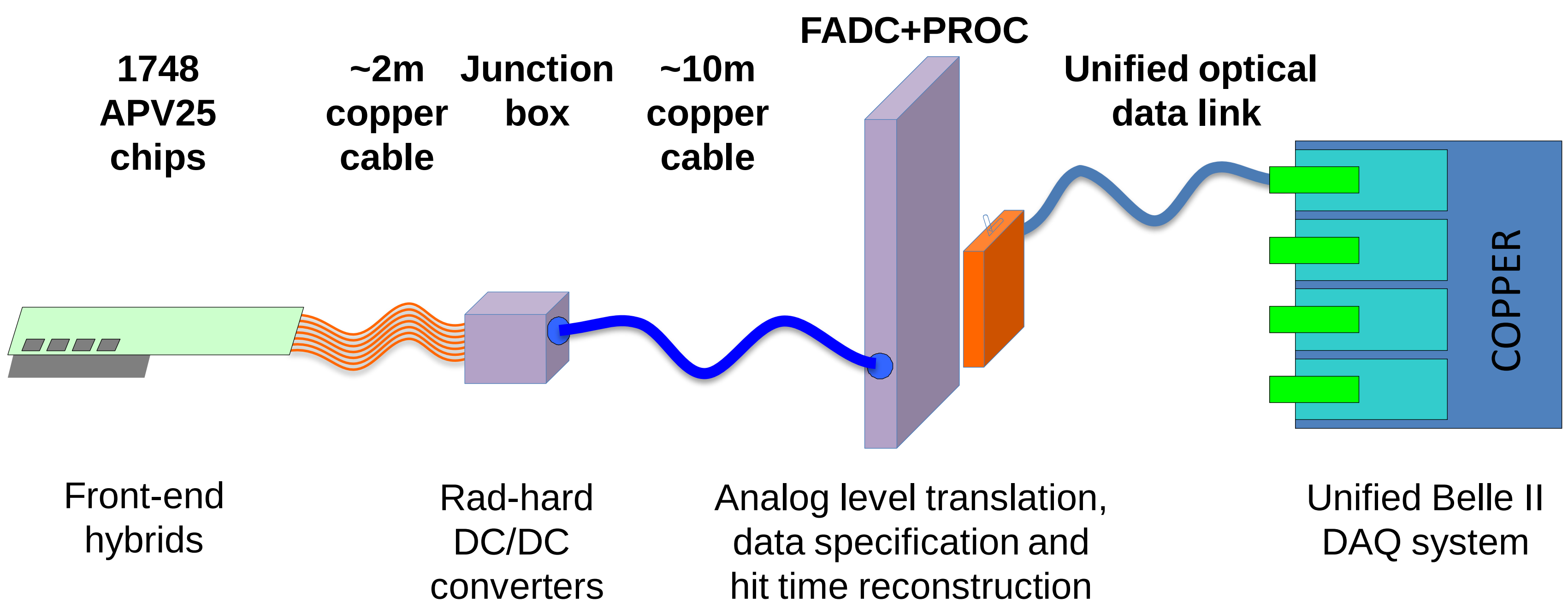




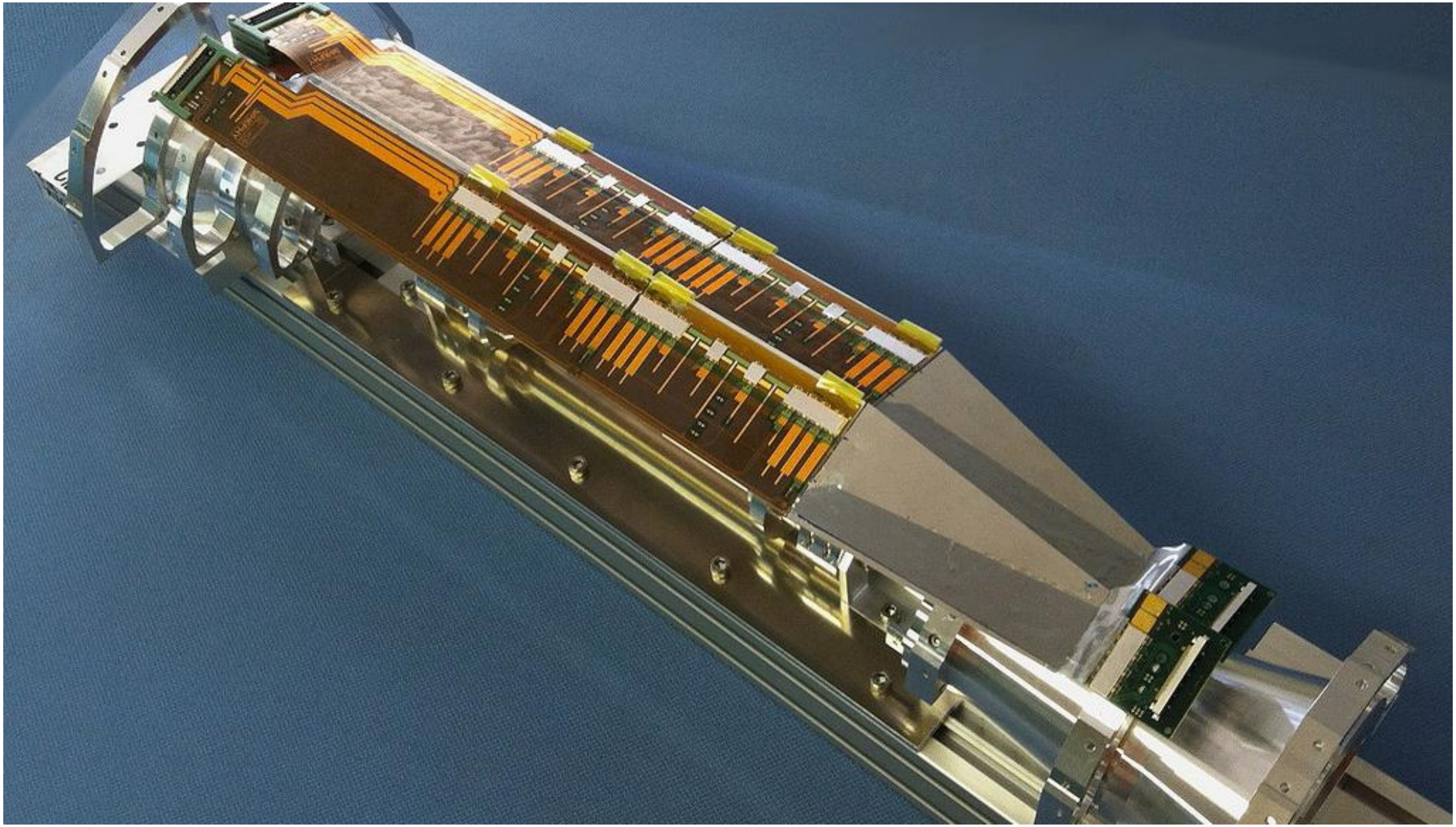
- Dark colors: non-irradiated, Light colors: irradiated
- Four geometries: width of „virtual“ strip defined by p-stop
- Atoll pattern (half-wide) performs best, both irradiated and non-irradiated
  - Chosen for final sensor

Readout System Concept

- **Analog data transmission** up to FADC by copper cable
  - Signal conditioning using FIR (Finite Impulse Response) filter
- Prototype **readout system exists**
  - **Verified** in several **beam tests**
- **Final system to be ready for beam test at DESY in June, 2014**



Going real!

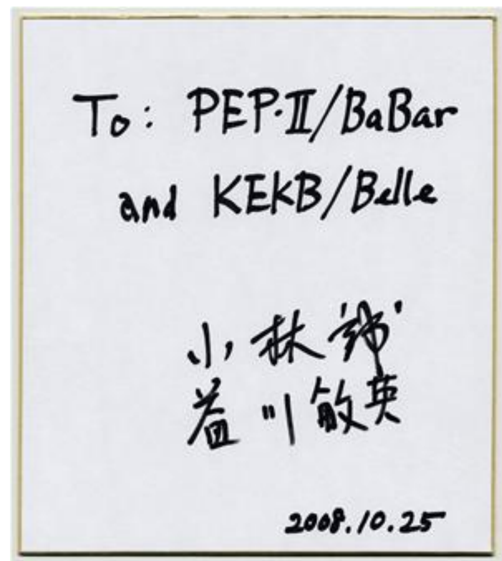


The Belle II Collaboration

A very strong group of ~400 highly motivated scientists!

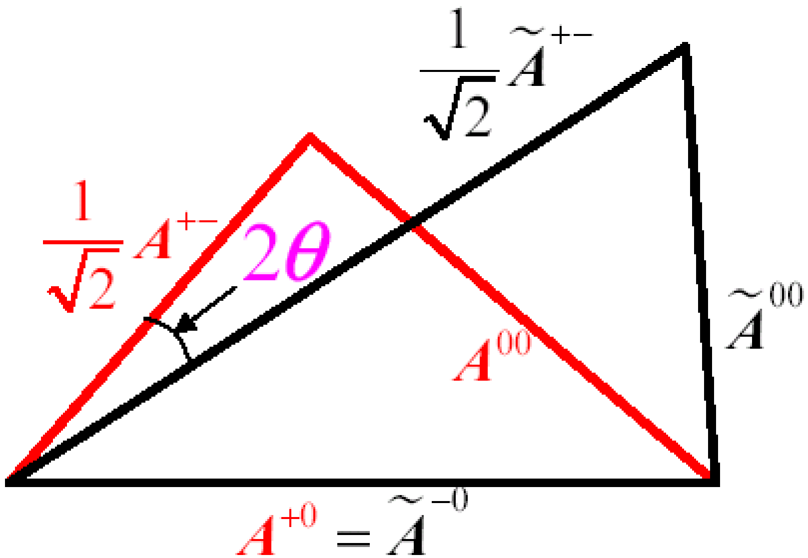
Summary

- Started Data Taking in 1999 and continued till summer of 2010.
- Recorded peak luminosity of experiment 2.11 x 10^{34} cm^{-2} s^{-1} , which is world record itself.
- Successfully established the presence of CP violation for first time in B-meson system.
- Nobel prize in 2008 for Kobayashi & Maskawa for their theoretical work on CP violation.
- Belle2 (next generation experiment on CP violation in LHC era) is approved and R&D is underway.
- Major upgrade at KEK in 2010-16 → Super B factory, L x 40
- Essentially a new project, all components have to be replaced of existing system.
- The project has a sizeable Indian participation.
- Expecting a new, exciting era of discoveries, complementary to LHC



http://www-public.slac.stanford.edu/babar/Poster/slac_nobel_poster_2008.pdf

Effect of Penguin on ϕ_2



M. Gronau and D. London, PRL 65, 3381 (1990)

Isospin relation

$$S_{\pi\pi} = \sqrt{1 - A_{\pi\pi}^2}\,\sin(2\phi_2 + 2\theta)$$

	Amplitude for
$A^{+-}\,(\overline{A}^{+-})$	$B^0\,(\overline{B}^0) \rightarrow \pi^+\pi^-$
$A^{00}\,(\overline{A}^{00})$	$B^0\,(\overline{B}^0) \rightarrow \pi^0\pi^0$
$A^{+0}\,(\overline{A}^{-0})$	$B^+\,(B^-) \rightarrow \pi^+\pi^0\,(\pi^-\pi^0)$

$$\tilde{A}^{ij} = e^{2\phi_3}\,\overline{A}^{ij}$$

EW Penguin neglected
(isospin breaking)

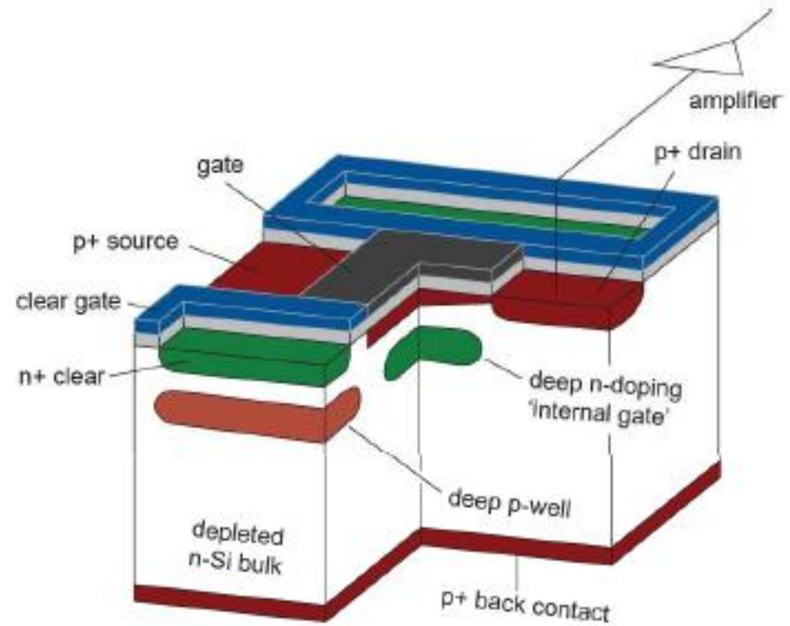
Requirement for a Pixel Detector

- **physics performance requirements**
  - excellent hit resolution
  - low material budget (low multiple scattering)
  - operate close to the interaction point
- **detector technology requirements**
  - fast readout
  - radiation hard
  - high signal to noise ratio
  - digest high background rate

Pixel Detector based on Depleted p-channel FET technology

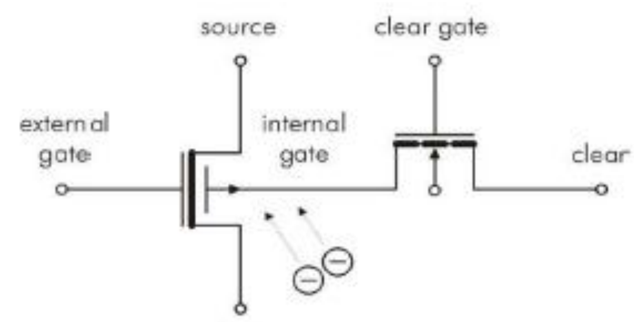
DEPFET – DEpleted P-channel Field Effect Transistor

- Each pixel is a p-channel FET on a completely depleted bulk (sideward depletion). Charge is collected by drift
- A deep n-implant creates a potential minimum for electrons under the gate (internal gate)

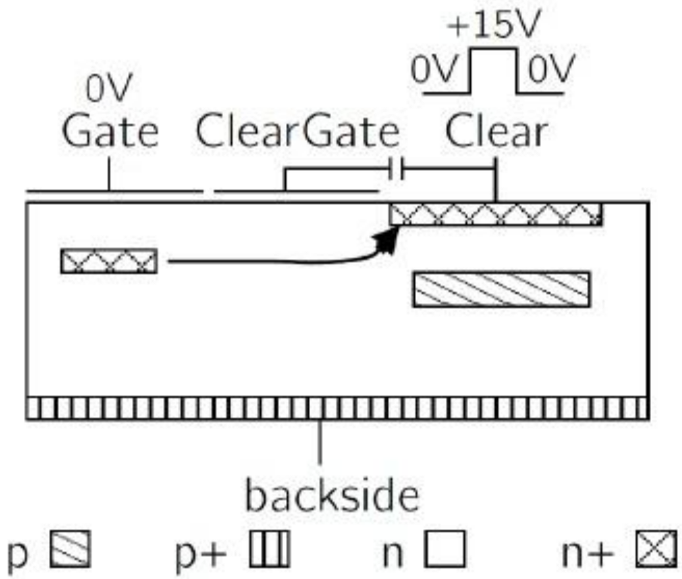


- Signal electrons accumulate in the internal gate and modulate the transistor current ($g_q \approx 400 pA/e^-$)
- Accumulated charge can be removed by a clear contact

- Detection and internal amplification
- Good signal-to-noise ratio
- Low power consumption
- Thin detectors



The CLEAR mechanism



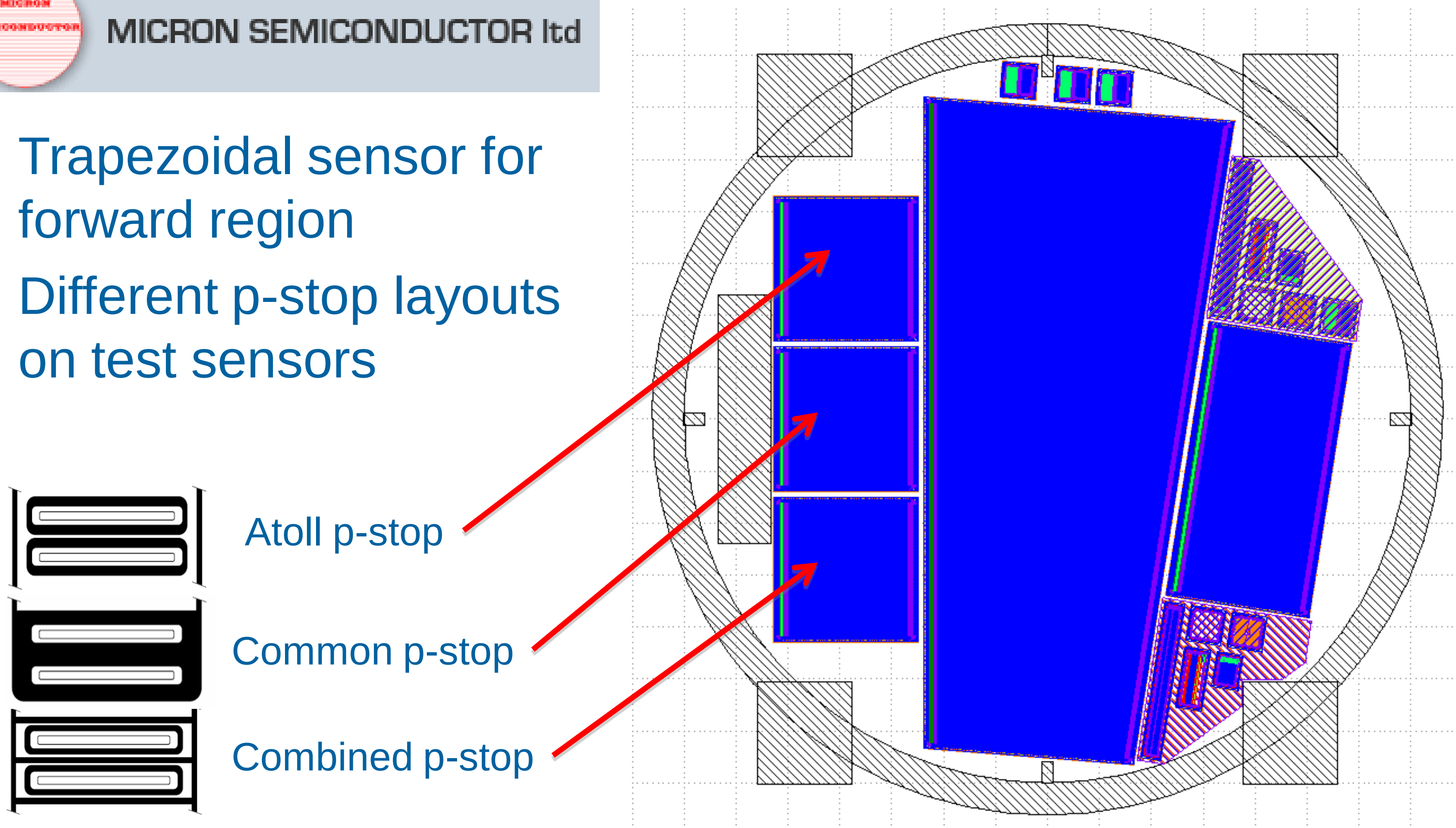
- The n^+ implant is a potential minimum for e^-
- The charge stored in the internal gate is removed applying a high positive voltage
- The e^- drift towards the clear contact and are then removed
- p-doped region used to shield the clear contact
- *Clear-gate structure* used to lower the potential barrier between the internal gate and the clear

BACK-UP

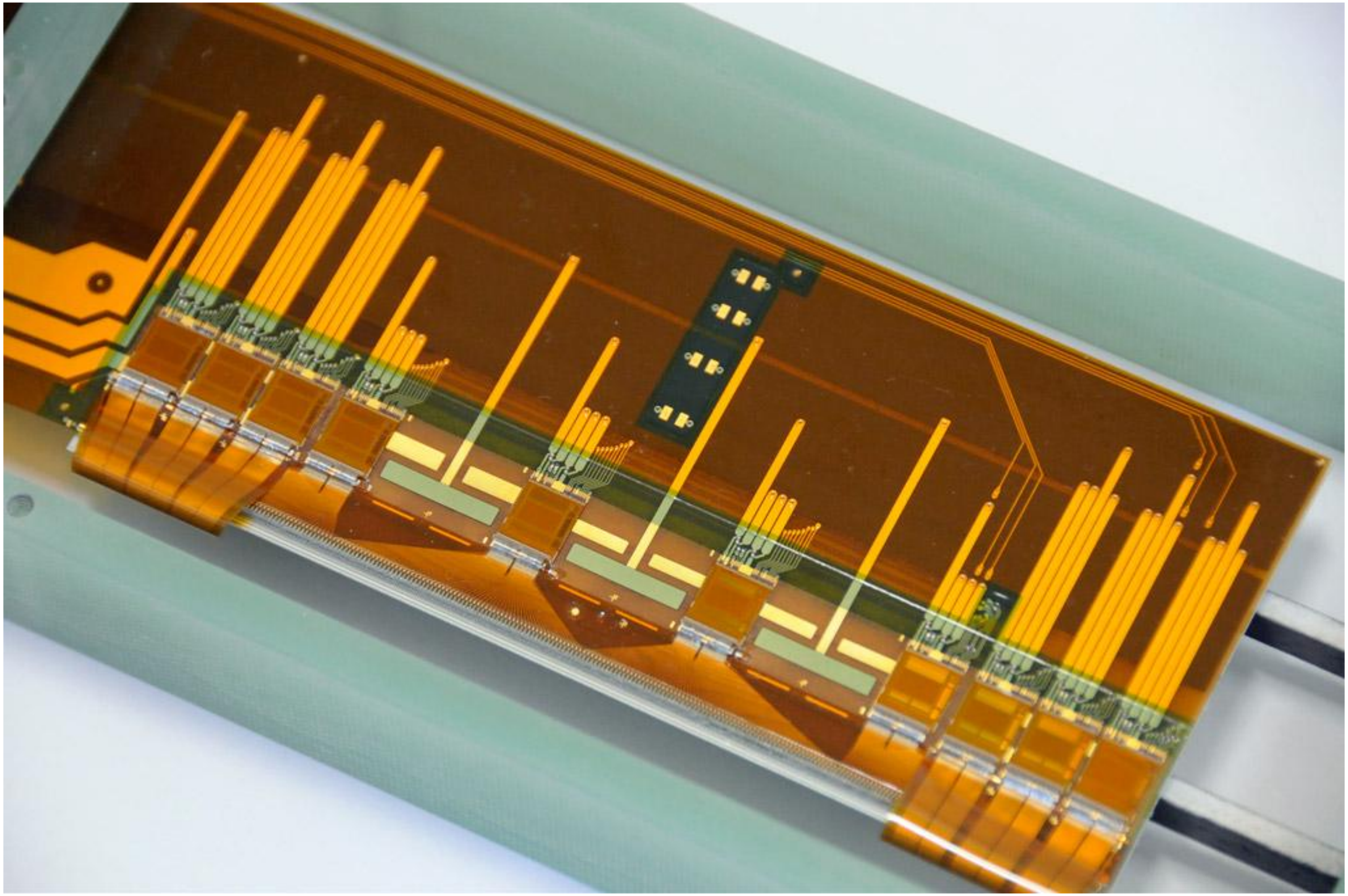
Trapezoidal Sensors for Forward Region

MICRON SEMICONDUCTOR ltd

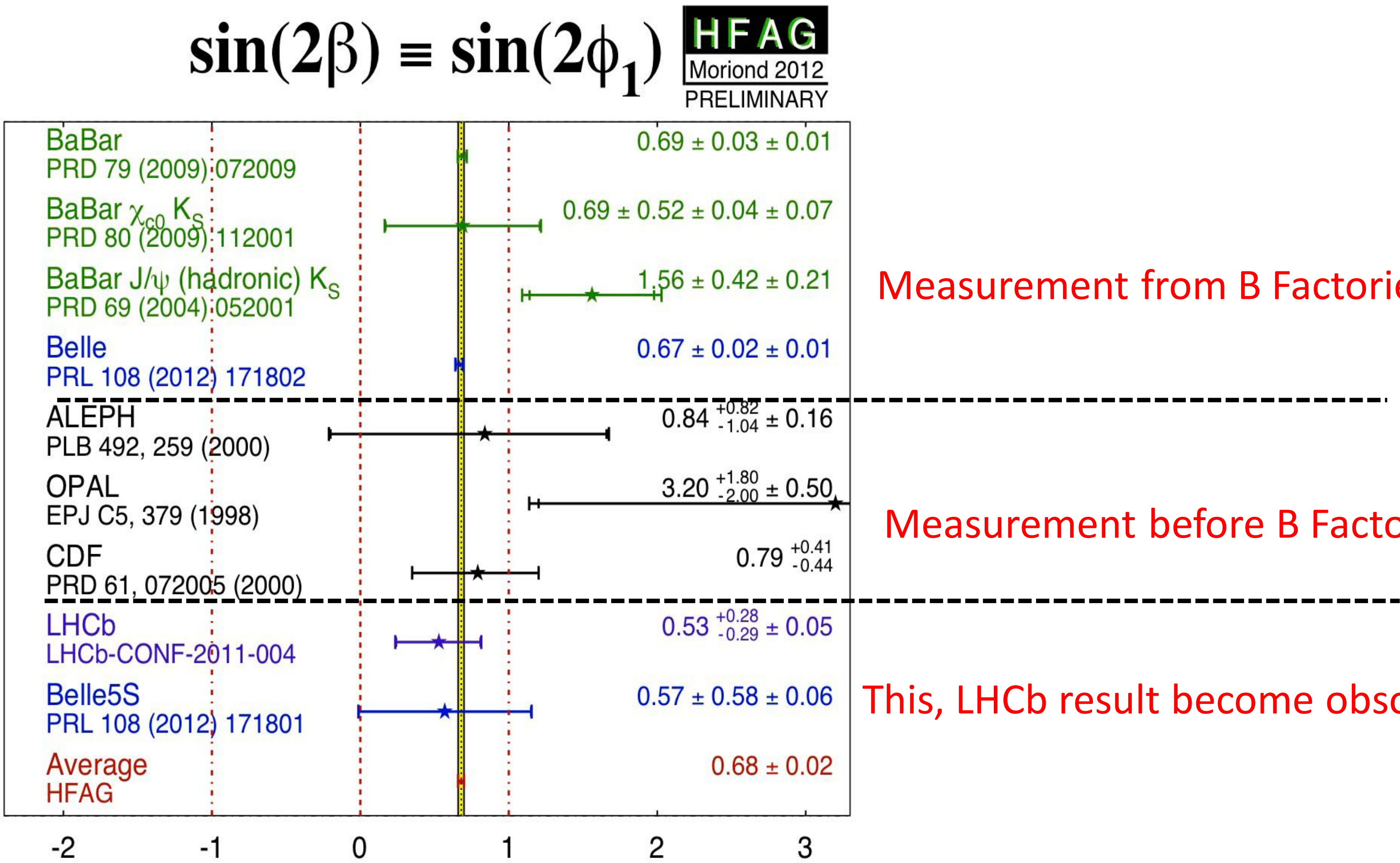
- Trapezoidal sensor for forward region
- Different p-stop layouts on test sensors



Origami Module with 6" HPK DSSD



Known as a firm SM reference



Measurement from B Factories

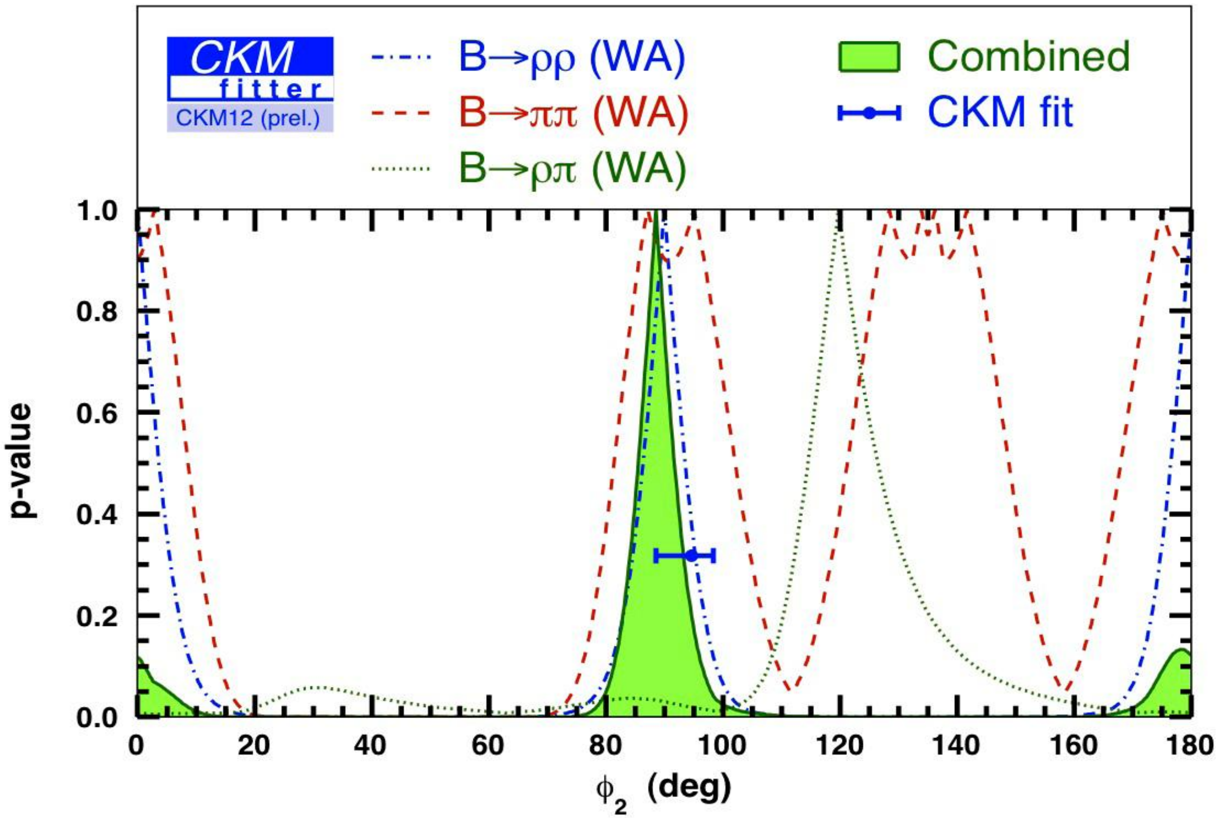
Measurement before B Factories

This, LHCb result become obsolete

B factories: a success story

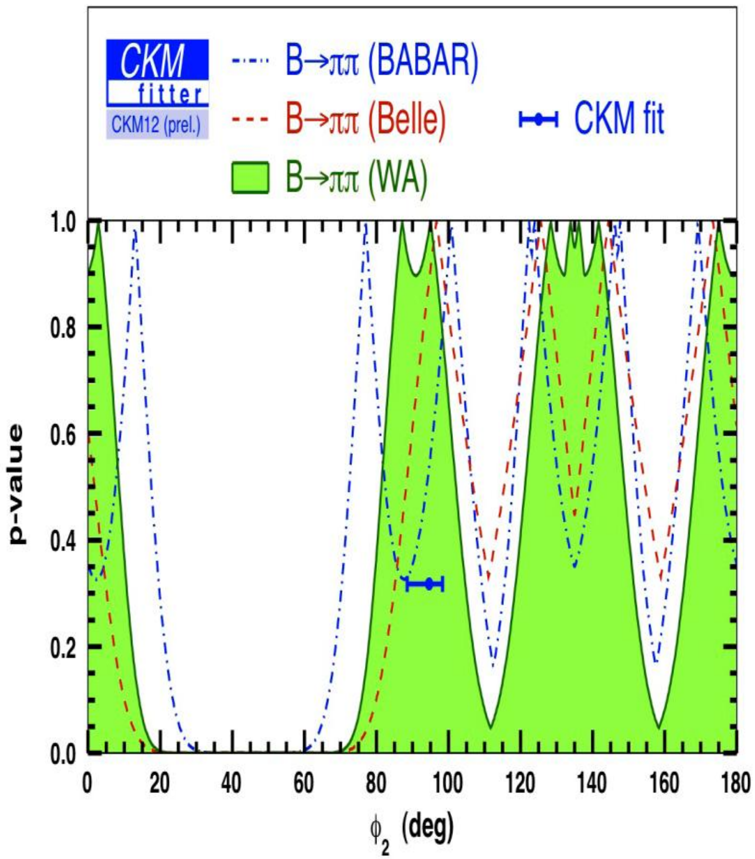
- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., B→**τυ**, D**τυ**) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in b→s transitions: probe for new sources of CPV
- Observation of new hadrons /spectroscopy
- 2008 Noble Prize to Kobayashi and Maskawa based on Belle Results

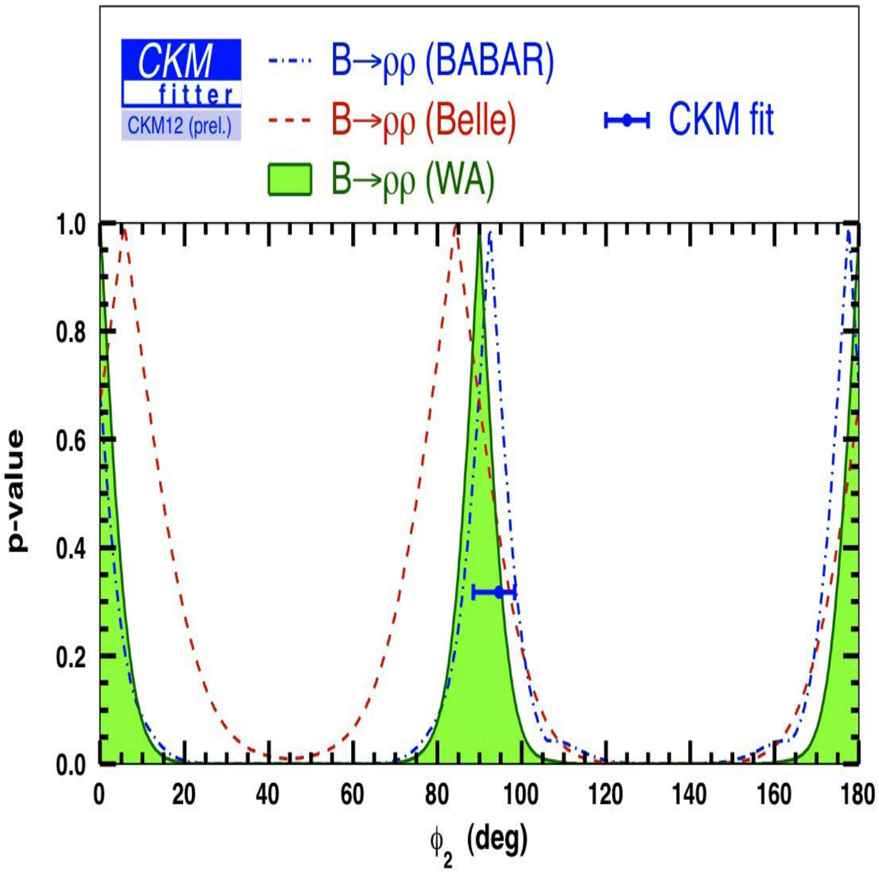
New constraint by ππ/ρρ/ρπ modes



$\alpha=\phi_2=(88.5\ {+4.7}/{-4.4})°$

New constraint by $\pi\pi/\rho\rho$ modes





For $\pi\pi$ mode, isospin triangle is found to properly close.

For $\rho\rho$, isospin triangle is flat, thus no plateau in p-value plot.

Symmetries

Nature and its Law: ~ Symmetry = Beauty

P, C, T : most Fundamental Symmetry

P : Parity = Space inversion

C : Charge conjugate (Particle $\leftrightarrow$ Anti-particle)

[Lagrangian $\rightarrow$ Hermitian conjugate]

T : Time reversal

CPT Theorem

Lorentz invariant local quantum field theory $\rightarrow$ CPT symmetry

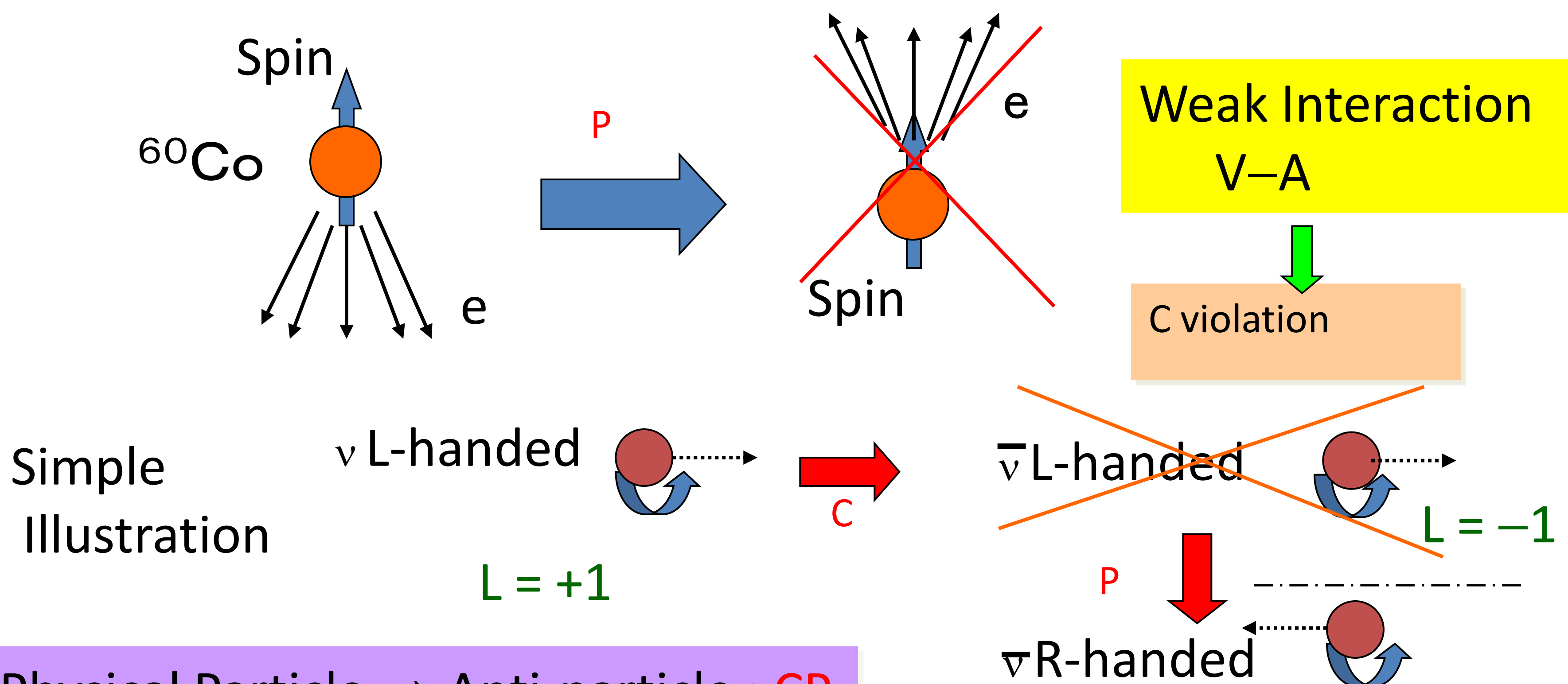
$\Rightarrow$ Particle $\leftrightarrow$ Anti-particle: Mass and Lifetime are identical

P& C Violation

P Violation

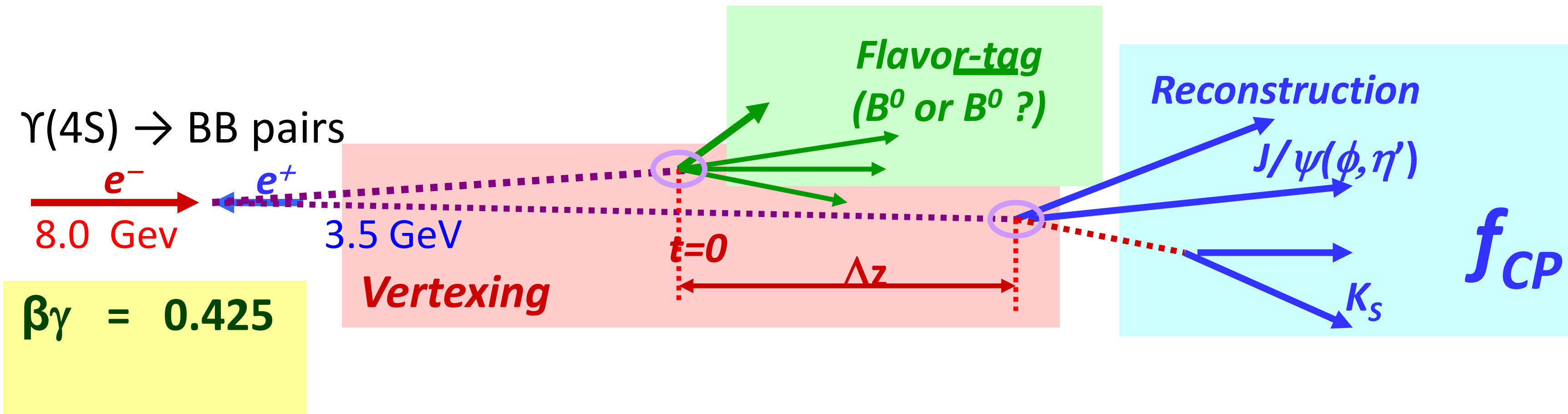
1956: Lee-Yang predict P violation [PR 104, 254]

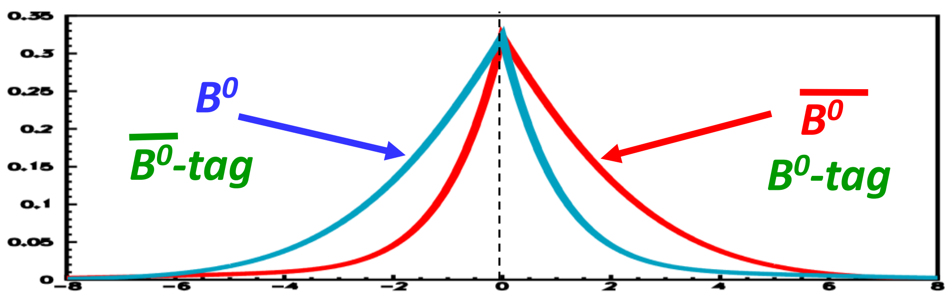
1957: discovered by C.S.Wu in ^{60}Co β-decay [PR 105, 1413]



Physical Particle → Anti-particle : CP

Time Dependent CP Violation





$$\Delta t \approx \Delta z / c\beta\gamma$$

fit

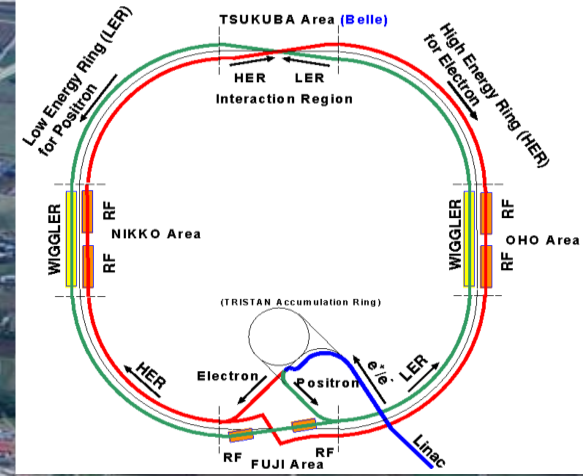
Extract CPV

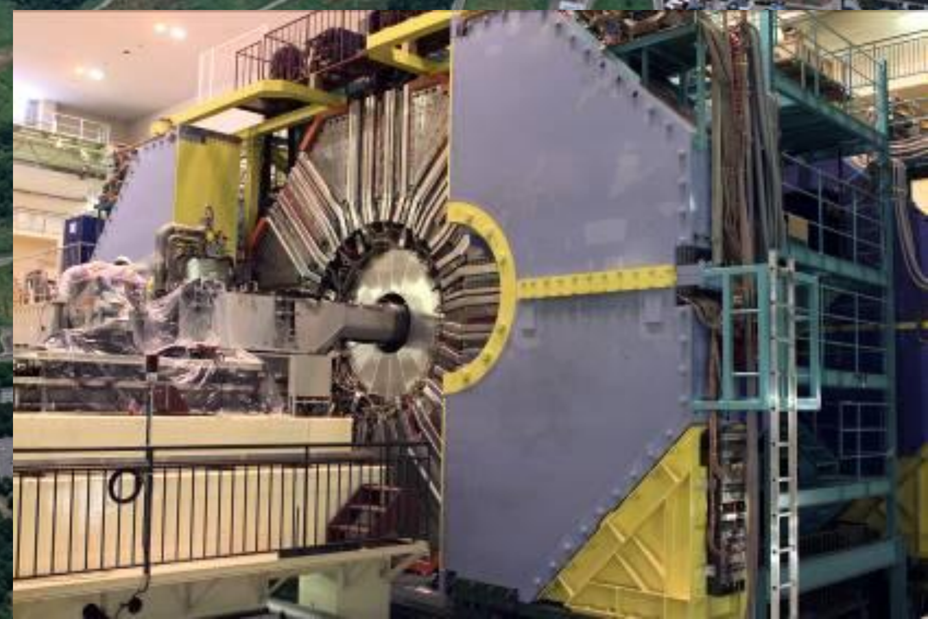
$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B}^0(\Delta t)\to f_{CP}) - \Gamma(B^0(\Delta t)\to f_{CP})}{\Gamma(\overline{B}^0(\Delta t)\to f_{CP}) + \Gamma(B^0(\Delta t)\to f_{CP})} = S_{f_{CP}}\sin(\Delta m\Delta t) + A_{f_{CP}}\cos(\Delta m\Delta t)$$

$$S_{f_{CP}} = \frac{2\,Im(\lambda)}{|\lambda|^2+1} \qquad A_{f_{CP}} = \frac{|\lambda|^2-1}{|\lambda|^2+1} \qquad \lambda = \frac{q}{p}\frac{\overline{A}(f_{CP})}{A(f_{CP})}$$

$$-C_{f_{CP}} = A_{f_{CP}} \qquad |\lambda| = 1 \text{ if no DCPV}$$

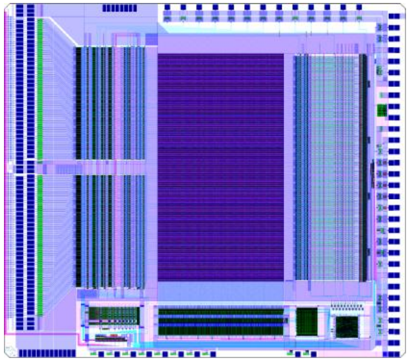
How to do it?
→ upgrade KEKB and Belle

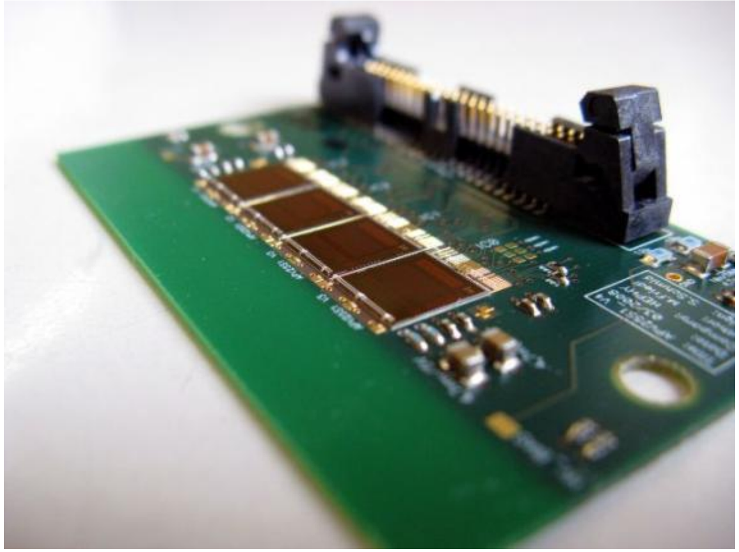




Readout Chip: APV25

- Developed for **CMS** (LHC) by *Imperial College* London and *Rutherford Appleton Lab*
  - 70,000 chips installed
- 0.25 µm CMOS process (**>100 MRad tolerant**)
- 128 channels
- **192 cell analog pipeline**
  → no dead time
- **50 ns shaping time** → low occupancy
- **Multi-peak mode** (read out several samples along shaping curve)
- **Noise:** 250 e + 36 e/pF
  → must minimize capacitive load!!!





Physics Case for SuperKEKB

Next generation: Super B factories → Looking for New Physics i.e. Physics beyond Standard Model

→ Need much more data (two orders!)

→ In November, 2010 KEK Management approved the up gradation of BELLE experiment viz. BELLE → BELLE II and KEKB → SuperKEKB

- ~100 M US $ for machine approved in 2010 -- Very Advanced Research Support Program (FY2010-2012)
- Full approval by the Japanese government in December 2010; the project was finally in the JFY2011 budget as approved by the Japanese Diet end of March 2011
- Most of non-Japanese funding agencies have also already allocated sizable funds for the upgrade of the detector.
- Indian contribution in the project is very significant. A budget of Rs. 300 million is under the consideration of DST and DAE.

	Inner layer (L1)	Outer layer (L2)
# modules	8	12
Distance from IP (cm)	1.4	2.2
Thickness (μm)	75	75
# pixels	768 x 250	768 x 250
Total # pixels	3.072 M	4.608 M
Pixel size (μm²)	55 x 50 60 x 50	70 x 50 85 x 50
Sensitive area (mm²)	44.8 x 12.5	61.44 x 12.5