Results of same-sign dilepton charge asymmetry from Belle and BaBar

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Outline

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  - Physics of B_d^0-$\overline{B}_d^0$ mixing dilepton charge asymmetry
- Results of same-sign dilepton charge asymmetry from B-factories
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- Conclusions

Introduction
B-factories, Belle and BaBar

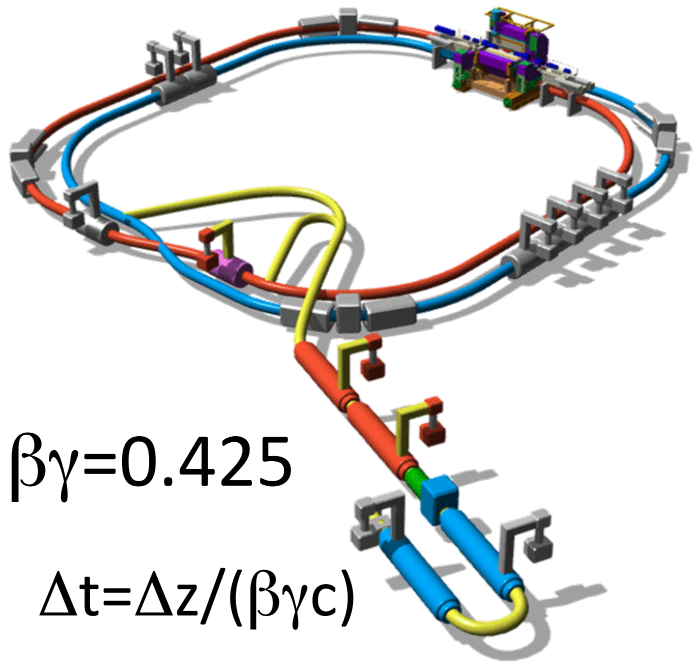
KEKB at KEK

8 GeV e^- and 3.5 GeV e^+
±11mrad crossing

on resonance of Υ(4S)~10.58GeV

Υ(4S) : $q\bar{q}$(continuum)= 1:3

Br(Υ(4S) →$B\bar{B}$)>96%



βγ=0.425

Δt=Δz/(βγc)

$L_{peak} = 2.1 \times 10^{34}\ \mathrm{sec}^{-1}\mathrm{cm}^{-2}$

>Twice of the design Luminosity !

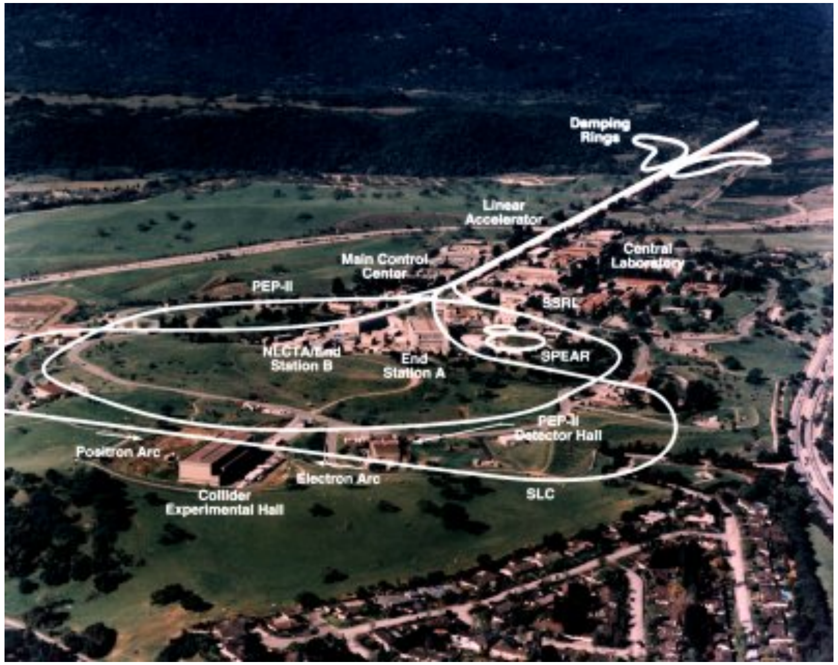
Producing enormous $B\bar{B}$ pairs copiously

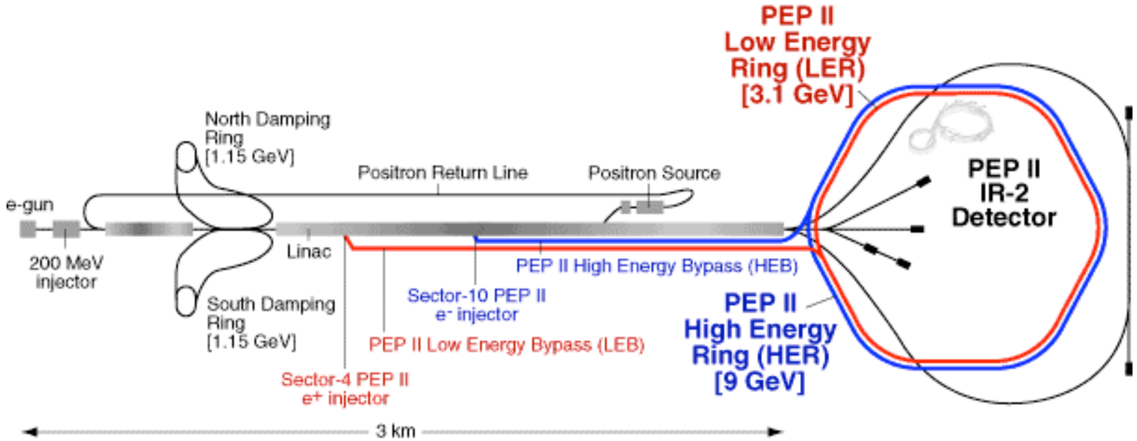
→ B-factory

PEP-II at SLAC

9 GeV e^- and 3.1 GeV e^+

on resonance of Υ(4S)~10.58GeV

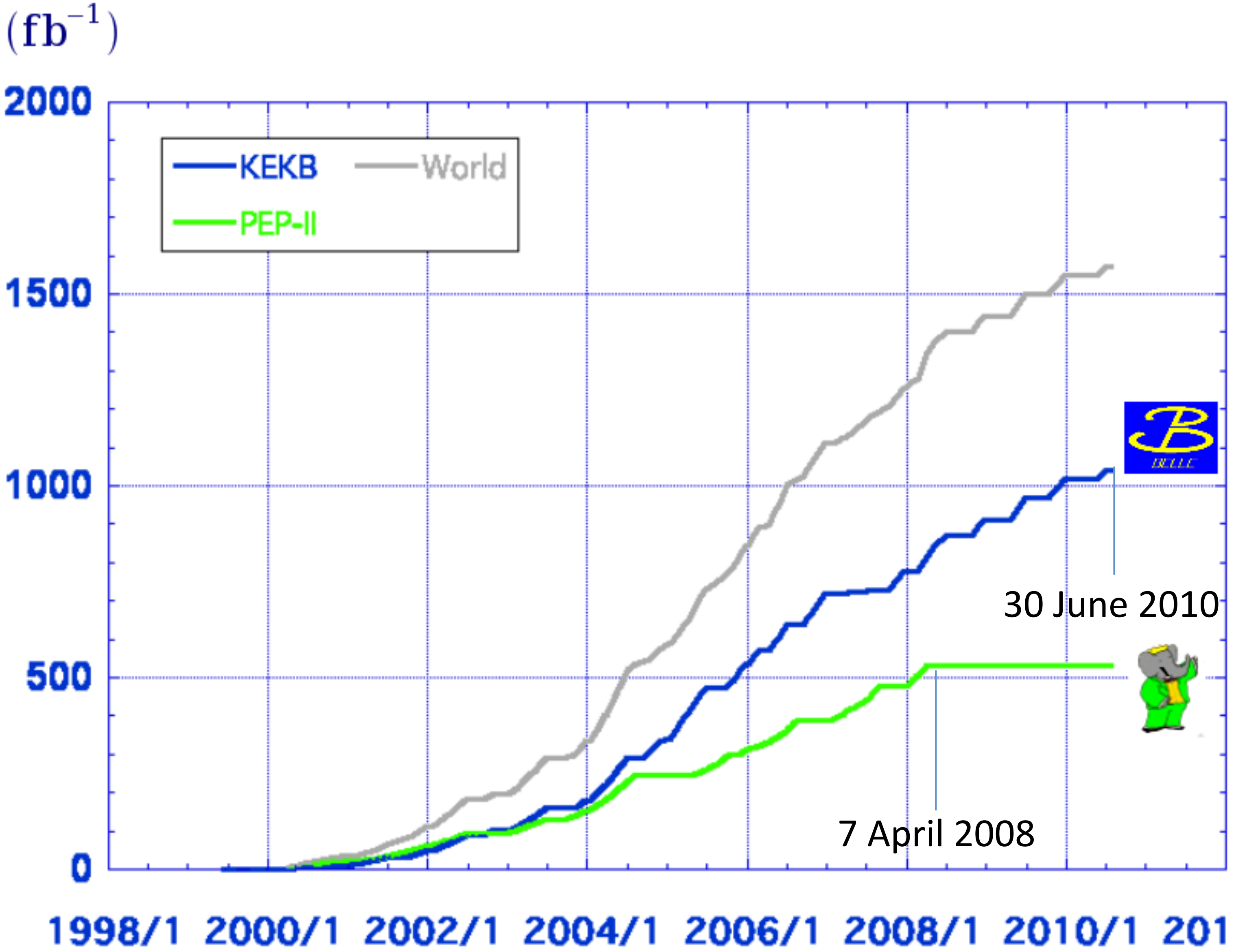




$L_{peak} = 1.2 \times 10^{34}\ sec^{-1}cm^{-2}$

$\beta\gamma$=0.55

Luminosity at B factories



> 1 ab^{-1}

On resonance:

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

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

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

$\Upsilon(2S)$: 24 fb^{-1}

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

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

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

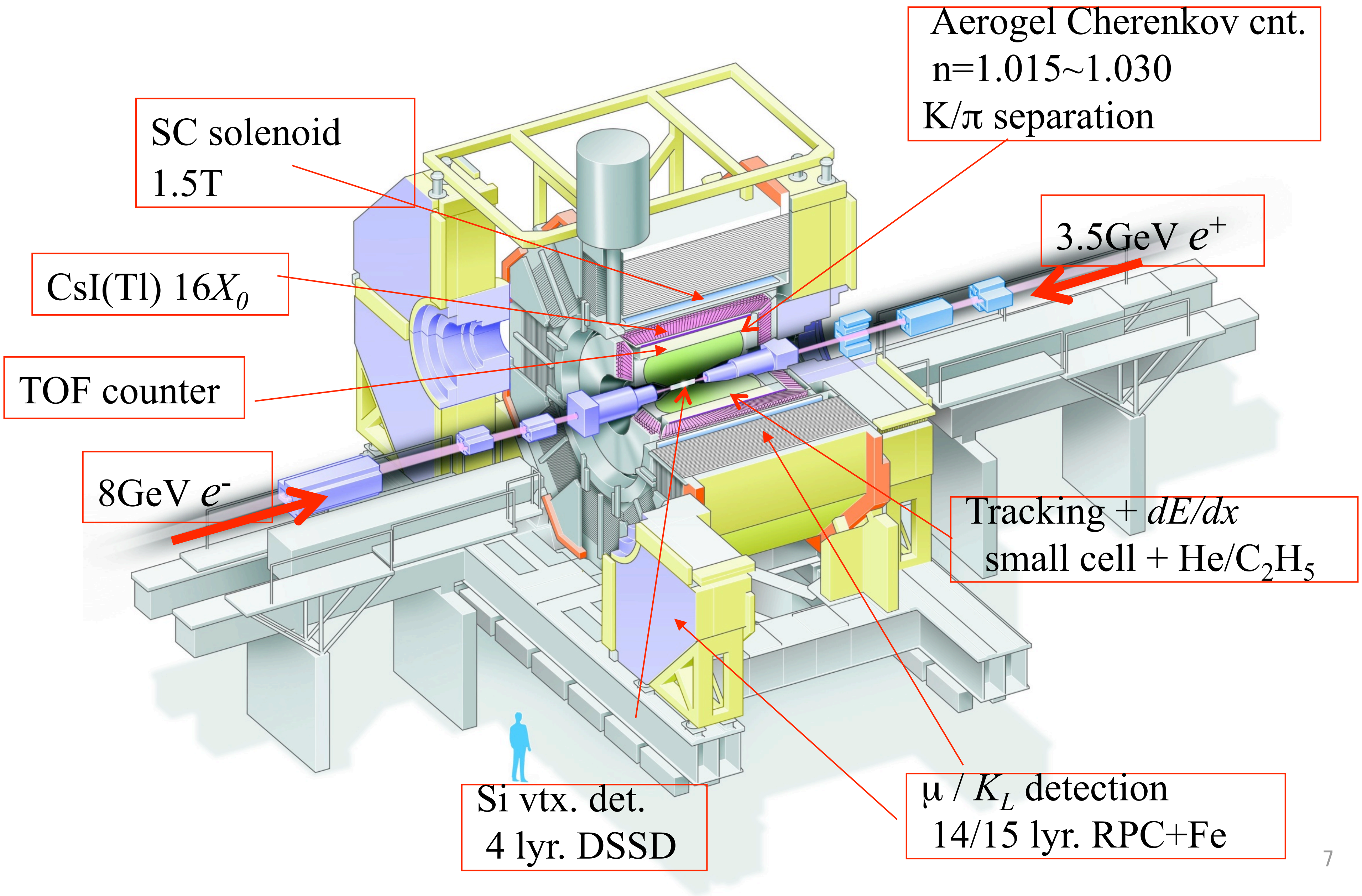
$\Upsilon(3S)$: 30 fb^{-1}

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

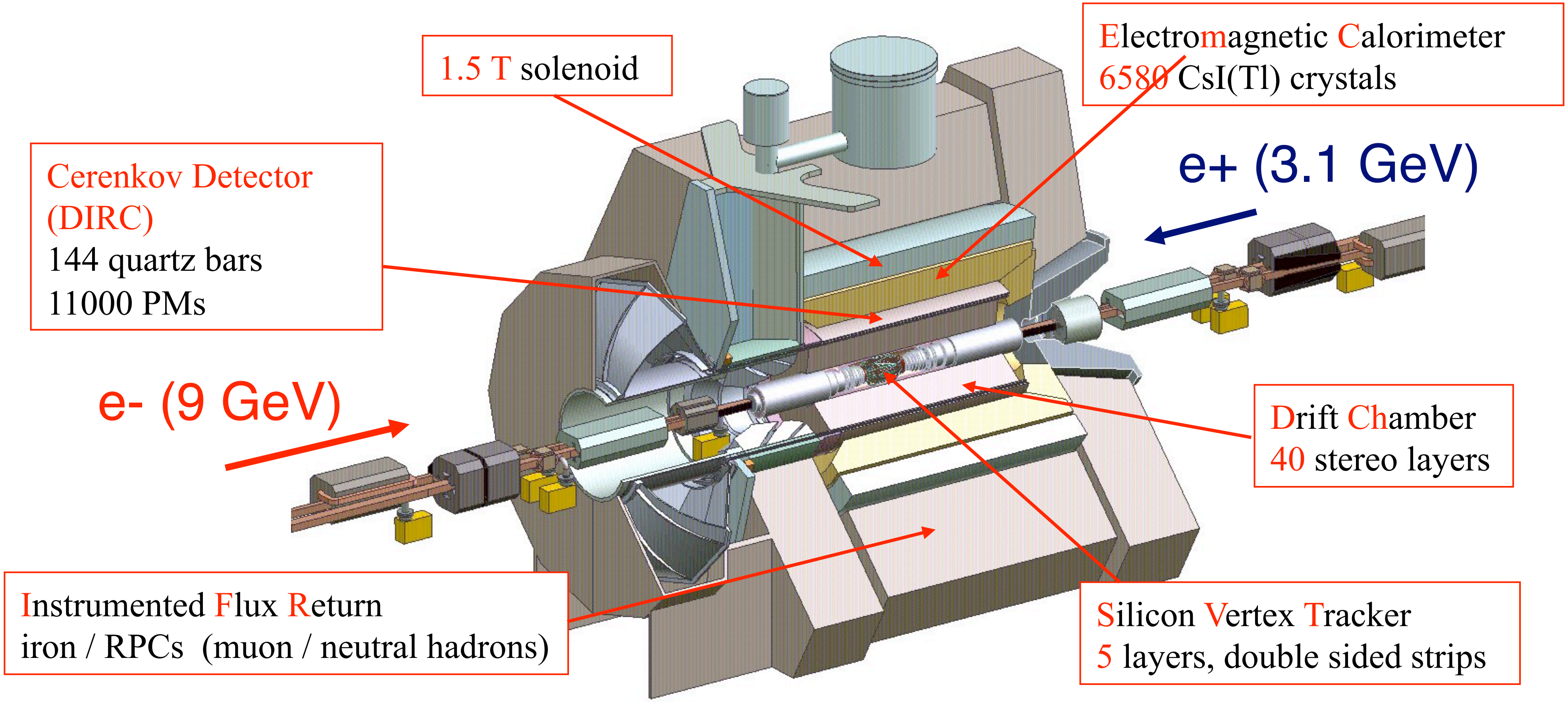
Off resonance:

~ 54 fb^{-1}

Belle Detector



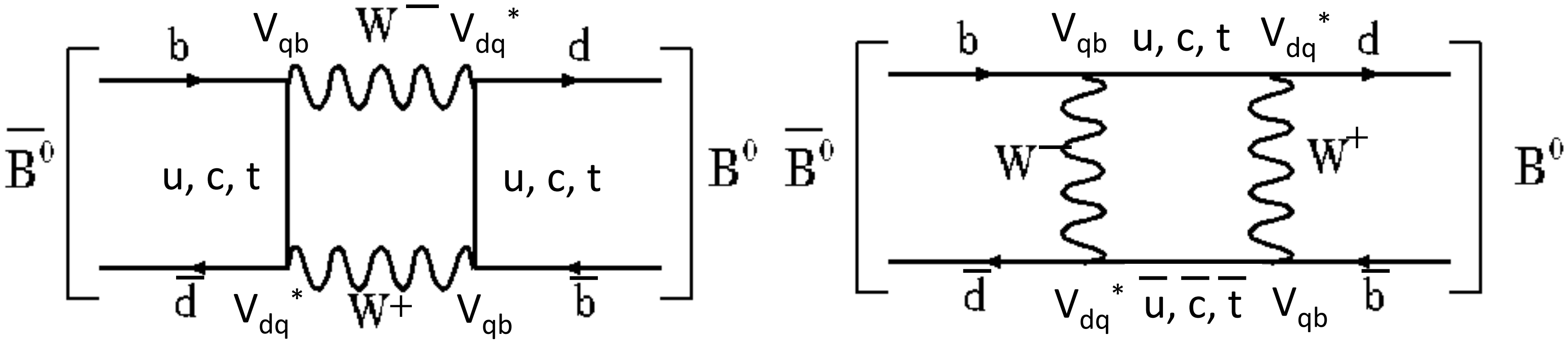
The BaBar Detector



Introduction

Physics of B_d^0-$\bar{B}_d^0$ mixing dilepton charge asymmetry

B_d^0-$\overline{B}_d^0$ mixing



A general state of neutral B-meson can be written as

$$|\psi(t)\rangle = a(t)\,|B^0\rangle + b(t)\,|B^0\rangle$$

We can evolves the state with Schrödinger eq.

$$i\,|\dot{\psi}\rangle = H\,|\psi\rangle$$

The equation can be re-written the matrics form

$$i\,\dot{\psi} = H\,\psi$$

The solution can be found by diagonalizing the matrics.

$$H\,\psi = \lambda\psi$$

B_d^0-$\overline{B}_d^0$ mixing

The eigen value of the equation can be expressed with mass and decay matrics elements supposing CPT-invariance.

$$\lambda_{\pm} = M_{\pm} - i\Gamma_{\pm}/2$$

The mass eigenstate are composed of two flavor eigenstates

$$|B^H\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$
$$|B^L\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

Where $|p|^2+|q|^2=1$

B_d^0-$\bar{B}_d^0$ mixing

We can evolve the time at t using λ

$$|B^0(t)\rangle = f_+(t)|B^0\rangle + (q/p)f_-(t)|\bar{B}^0\rangle$$

$$|\bar{B}^0(t)\rangle = (q/p)f_-(t)|B^0\rangle + f_+(t)|\bar{B}^0\rangle$$

Where $f_\pm = [\exp(-i\lambda_+ t) \pm \exp(-i\lambda_- t)]/2$

$$(q/p) \fallingdotseq V_{td}/V_{td}^*$$

Dilepton charge asymmetry

The time-dependent decay rate for same-sign dileptons can be calculated using the equations of previous slide as below.

$$\Gamma_{\Upsilon(4S)\to\ell^+\ell^+}(\Delta t) = \frac{|A_\ell|^4}{8\tau_{B^0}} e^{-|\Delta t|/\tau_{B^0}} \left|\frac{p}{q}\right|^2 \left[\cosh\left(\frac{\Delta\Gamma}{2}\Delta t\right) - \cos(\Delta m_d \Delta t)\right]$$

Thus, we can get the time integrated asymmetry

$$A_{\rm sl} \equiv \frac{\Gamma_{\Upsilon(4S)\to\ell^+\ell^+} - \Gamma_{\Upsilon(4S)\to\ell^-\ell^-}}{\Gamma_{\Upsilon(4S)\to\ell^+\ell^+} + \Gamma_{\Upsilon(4S)\to\ell^-\ell^-}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

The current predictions of |q/p| in the Standard Model are

$$2\times10^{-4} \lesssim |q/p|-1 \lesssim 6\times10^{-4}$$

Some NP scenarios indicate to be different with that of the SM

Results of same-sign dilepton charge asymmetry from B-factories

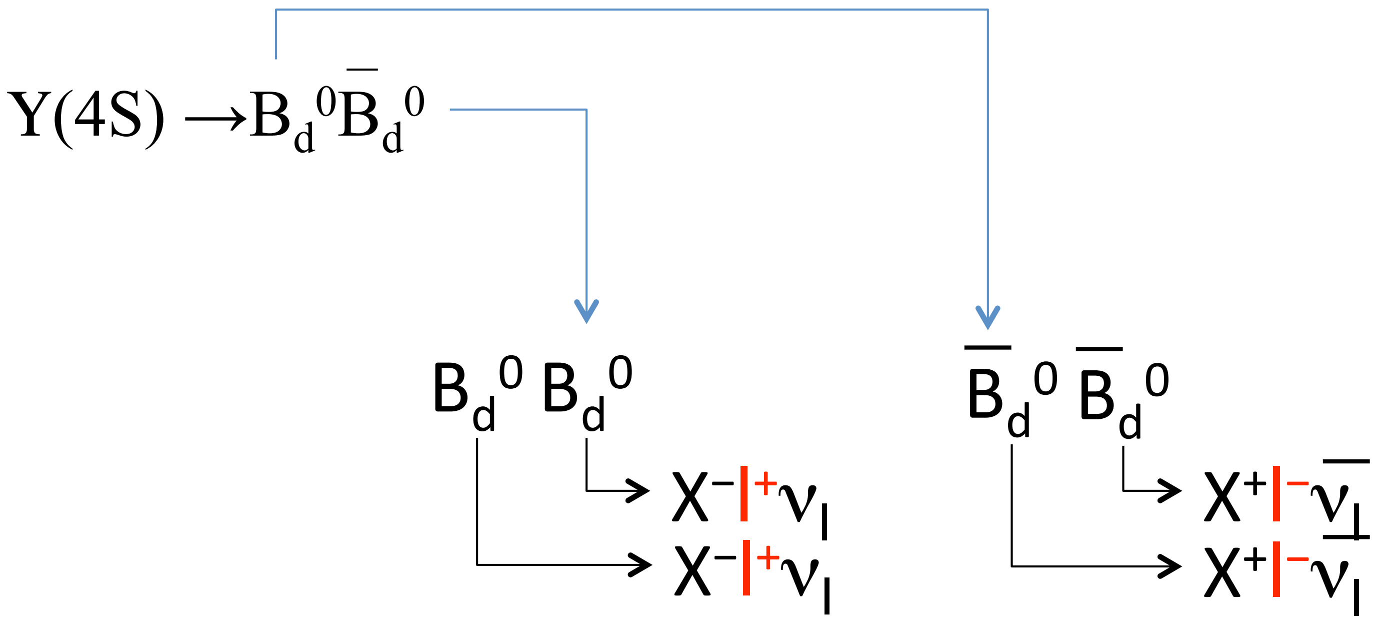
BELLE

E.Nakano et al. Physical Review D 73, 112002(2006)

BABAR

B.Aubert et al. Physical Review Letters 96, 251802(2006)

Signals

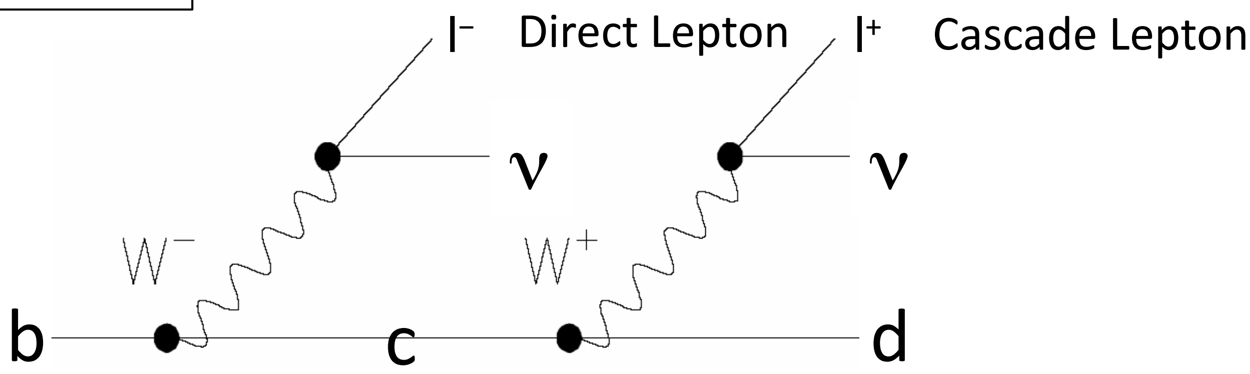


Charge of lepton from semileptonic decay determines B flavour at decay time

Backgrounds

Cascade decay

Also from $B^+ B^-$



- Dilepton in which one lepton comes from cascade decay.

unmixed $B_d^0 \ \overline{B}_d^0$

$\overline{B}_d^0 \rightarrow D^+ l^- \overline{\nu}_l$, $D^+ \rightarrow X^0 l^+ \nu_l$

$B_d^0 \rightarrow X^- l^+ \nu_l$

- Dilepton in which both lepton come from cascade decay.

mixed $\overline{B}_d^0 \ \overline{B}_d^0$

$\overline{B}_d^0 \rightarrow D^+ l^- \overline{\nu}_l$, $D^+ \rightarrow X^0 l^+ \nu_l$

$\overline{B}_d^0 \rightarrow D^+ l^- \overline{\nu}_l$, $D^+ \rightarrow X^0 l^+ \nu_l$

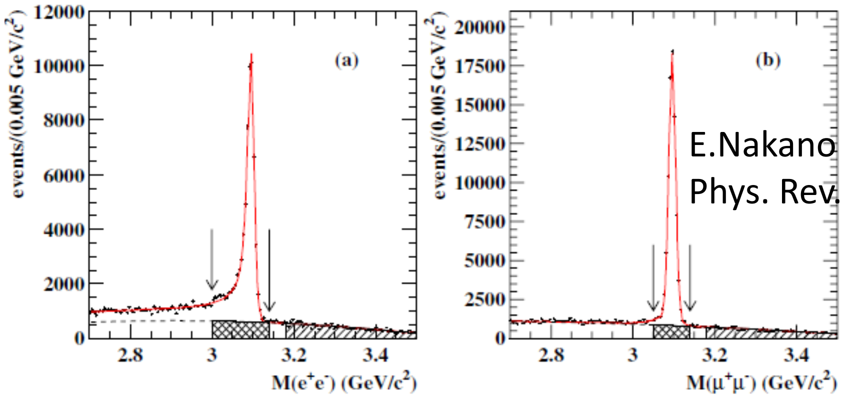
- Direct lepton and the cascade decay lepton stem from the same B

Backgrounds

Charmonium

J/ψ→ll veto

BaBar ψ(2S)→ll veto



BELLE

E.Nakano et al.
Phys. Rev. D 73, 112002(2006)

Continuum

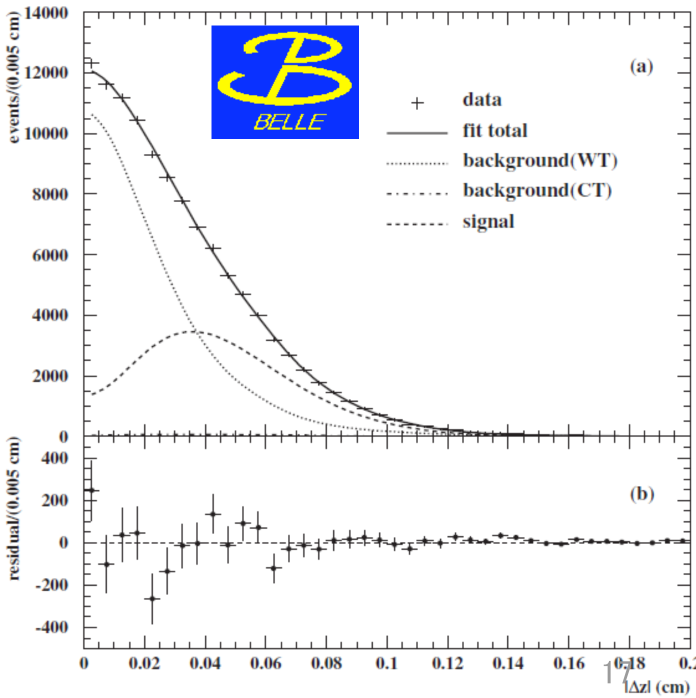
All possible combinations

BELLE

Casecade background fractions are fixed at the MC, signal and background fraction is float and determined with $|\Delta z|$ fit.

BaBar

Casecade background fractions are fixed at the MC and estimated from data.



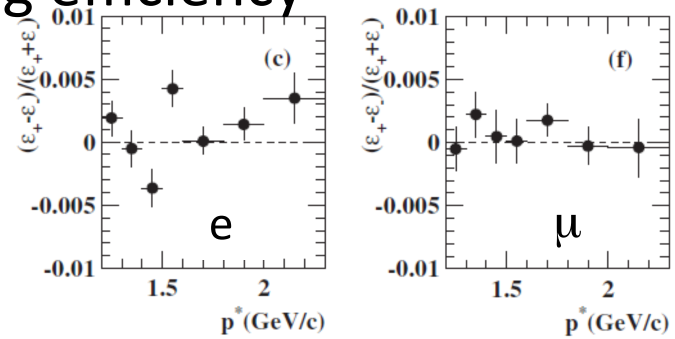
Asymmetry effect from detector

- Track finding efficiency

BELLE

e: < 0.5%

μ: < 0.5%



BABAR

e: 0.8±0.2%

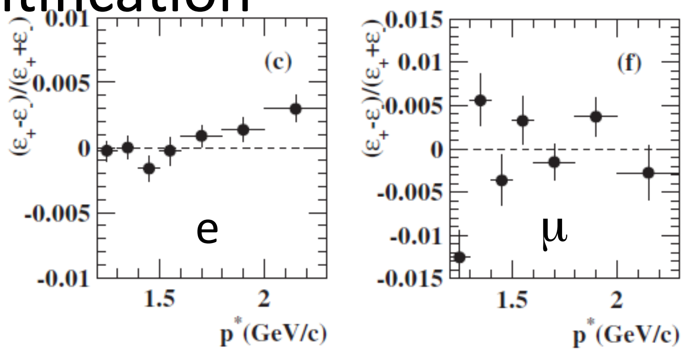
μ: 0.8±0.2%

- Lepton identification

BELLE

e: < 0.5%

μ: < 0.5%



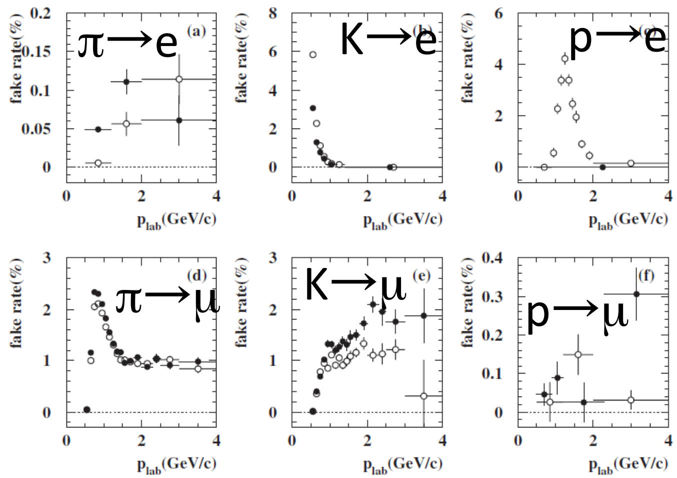
BABAR

e:
- 1.2% for direct lepton w/ higher p
- 0.8% for direct lepton w/ lower p
- 0.5% for casecade lepton w/ higher p
- 0.2% for casecade lepton w/ lower p

μ: float in the fit

- Hadron misidentification

BELLE



Open circle:
Negative charge

Filled circle:
Positive charge

BABAR

K→μ

p→e

The effect is included in the Lepton ID

Data selection at Belle

- Data sample: 85M B-pairs

- Event selection:

– Fox-Wolfram moments, at least 5 tracks, vertex in IR, Total Energy, Momentum, Opening angle of two tracks

– Tight lepton PID

– Photon conversion and J/ψ veto

TABLE I. Summary of the dilepton yields. The yields in Continuum are determined from the yields in Off-resonance by correcting for luminosity and cross section.

Combination	On-resonance positive	On-resonance negative	Off-resonance positive	Off-resonance negative	Continuum positive	Continuum negative
ee	9059	9028	11	11	96.2 ± 28.9	96.2 ± 28.9
$\mu\mu$	14672	14014	144	100	1259.2 ± 104.9	874.4 ± 87.4
$e\mu$	22802	22435	100	69	874.4 ± 87.4	603.4 ± 72.6
total	46533	45477	255	180	2229.8 ± 139.6	1574.0 ± 117.3

Corrections

- **Efficiency correction**

$$N^{\pm}_{\mathrm{det}}(p^*, \theta_{\mathrm{lab}}) = N^{\pm}_{\ell}(p^*, \theta_{\mathrm{lab}})\varepsilon^{\pm}_{\mathrm{trk}}(p^*, \theta_{\mathrm{lab}})\left\{\varepsilon^{\pm}_{\mathrm{pid}}(p^*, \theta_{\mathrm{lab}}) + \sum_{h=\pi,K,p} r^{\pm}_{h\ell}(p^*, \theta_{\mathrm{lab}})\eta^{\pm}_{h\ell}(p^*, \theta_{\mathrm{lab}})\right\}$$

- $N^{\pm}_{\mathrm{det}}$: #detected track
- $\varepsilon^{\pm}_{\mathrm{trk}}$: track finding eff.
- $r^{\pm}_{h\ell}$: hadron/lepton ratio (MC)
- $N^{\pm}_{\ell}$: #generated track
- $\varepsilon^{\pm}_{\mathrm{pid}}$: lepton id eff.
- $\eta^{\pm}_{h\ell}$: lepton id fake rate(data)

p^*…lepton momentum in e^+e^- center of mass

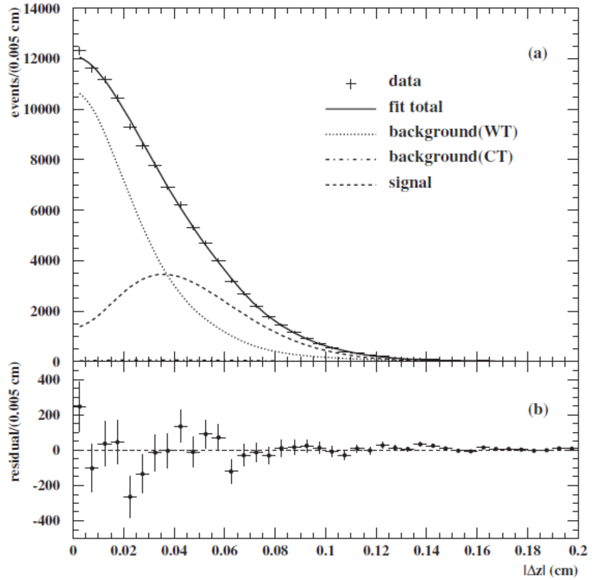
θ_{lab} …angle between lepton momentum direction and beam axis the in the lab.

- **Continuum correction**

To suppress the contribution from continuum, dilepton candidate yield is wighted by function as below. $Prob(BB) = f(p_1{}^*, p_2{}^*, \theta_1, \theta_2, \theta_{ll}{}^*, \Delta z)$

- **BB background correction**

Casecade background fractions are fixed at the MC, signal and background fraction is float and determined to fit for |Δz| distribution.



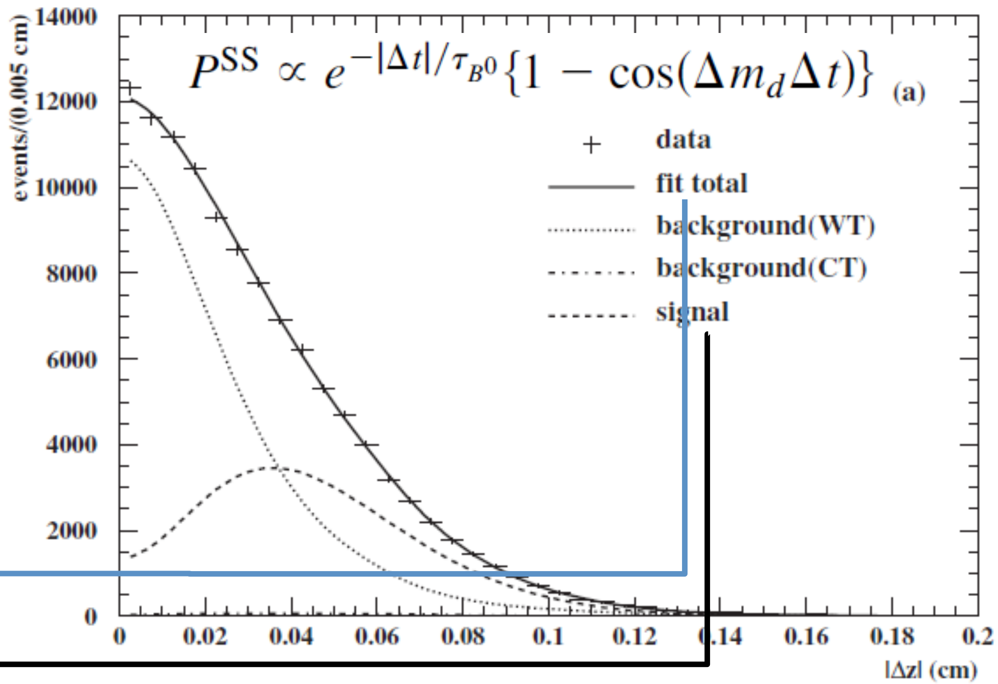
Fitting data at Belle

Using $N^{\pm\pm}(\Delta z) = N_s^{\pm\pm}(\Delta z) + N_b^{\pm\pm}(\Delta z)$

$$A_{\ell\ell}(\Delta z) = \frac{N^{++}(\Delta z) - N^{--}(\Delta z)}{N^{++}(\Delta z) + N^{--}(\Delta z)} = \frac{N_s^{++}(\Delta z) - N_s^{--}(\Delta z)}{N_s(\Delta z)} \frac{N_s(\Delta z)}{(N_s(\Delta z) + N_b(\Delta z))}$$

$$\approx A_{\rm sl}(\Delta z) d(\Delta z)$$

dilution factor $d(|\Delta z|) = N_S/N_{Total}(|\Delta z|)$



Result at Belle

A_{sl} = $(-1.1 \pm 7.9(\text{stat}) \pm 8.5(\text{syst}))\times 10^{-3}$

$|q/p|$ = $1.0005 \pm 0.0040(\text{stat}) \pm 0.0043(\text{syst})$

$|q/p|-1$ = $(0.5 \pm 4.0(\text{stat}) \pm 4.3(\text{syst}))\times 10^{-3}$

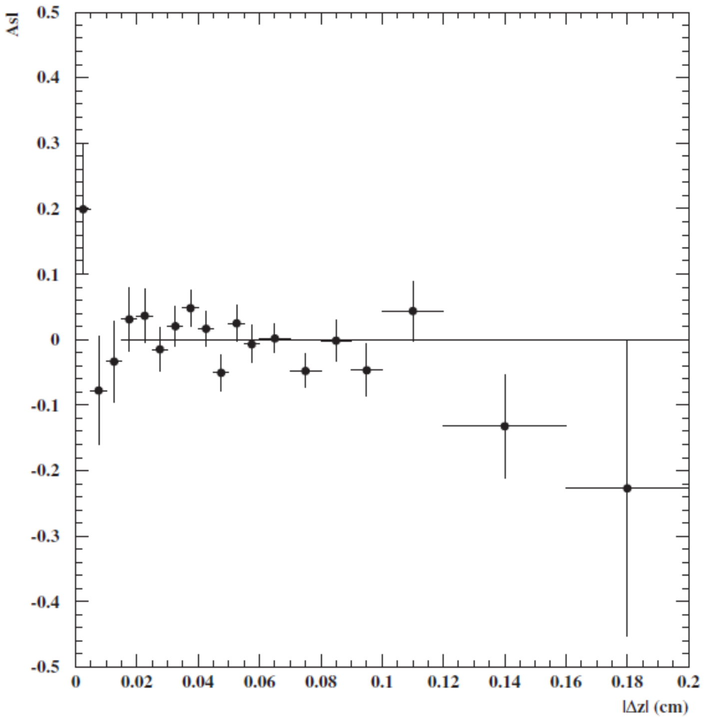


TABLE II. Source of systematic errors for the measurement of A_{sl}.

Category	Source	ΔA_{sl} $(\times 10^{-3})$
Event selection	Track selection	± 2.61
	$\cos\theta^*_{\ell\ell}$ cut	± 0.63
	Lepton pair veto	± 2.33
Continuum subtraction		± 4.88
Track corrections	Track finding efficiency	± 5.06
	Electron identification efficiency	± 0.56
	Muon identification efficiency	± 1.98
	Fake electrons	± 0.45
	Fake muons	± 0.81
	Relative multiplicity	± 0.56
	Model dependence	± 0.75
Δz fit for dileptons	Detector response function	± 0.07
	Δm_d	± 0.08
	τ_{B^0}	± 0.07
	69 μm smearing of background Δz	± 0.13
	Statistics of signal MC	± 0.01
	Statistics of background MC	± 0.19
	Dilution factor fitting range	± 0.04
	Assuming $N_b^{++} = N_b^{--}$	± 1.59
A_{sl} average	Δz range	± 1.30
Total		± 8.51

BABAR Data selection at BaBar

- Data sample: 232M B-pairs

- Event selection:

– Fox-Wolfram moments, invariant mass, aplanarity, track multiplicity

– Tight lepton PID

– Photon conversion and charmonium veto

→1.4×10^{6} events pass this dilepton selection

BaBar Data fitting at BaBar

Likelihood fit function is defined as below

fraction of continuum

$$\mathcal{L}(\Delta t) = (1+q_1 a_{f_1}^{cont})(1+q_2 a_{f_2}^{cont}) f_{cont}\mathcal{P}_{cont}$$ Continuum term

$$+(1-f_{cont})\{f_{+-}\mathcal{P}_{B^+B^-} + (1-f_{+-})\mathcal{P}_{B^0\overline{B}^0}\}$$ The other term

fraction of B^+B^- — $B^0\overline{B}^0$ term

$$\mathcal{P}_{B^0\overline{B}^0} = (1-f_{sig}^n)(1+q_1 a_{f_1}^{casc})(1+q_2 a_{f_2}^{casc})\mathcal{P}_{casc}^n$$ Cascade term

$$+f_{sig}^n(1+q_1 a_{f_1}^{dir})(1+q_2 a_{f_2}^{dir})\mathcal{P}_{sig}^n$$ signal term

$$\mathcal{P}_{B^+B^-} = (1-f_{sig}^c)(1+q_1 a_{f_1}^{casc})(1+q_2 a_{f_2}^{casc})\mathcal{P}_{casc}^c$$ B^+B^- cascade term

$$+f_{sig}^c(1+q_1 a_{f_1}^{dir})(1+q_2 a_{f_2}^{dir})\mathcal{P}_{sig}^c$$ B^+B^- term

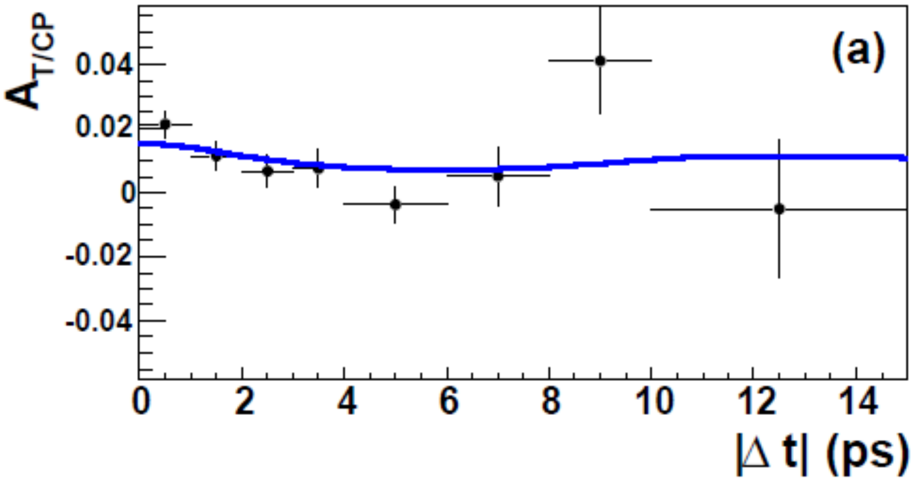
$$\mathcal{P}_{casc}^{n,c} = f_{other}^{n,c}\mathcal{P}_{other}^{n,c} + f_{1d1\tau}^{n,c}\mathcal{P}_{1d1\tau}^{n,c} + f_{sbc}^{n,c}\mathcal{P}_{sbc}^{n,c} + f_{obc}^{n,c}\mathcal{P}_{obc}^{n,c}$$

Tau decay term — Cascade decay term

Where q_1, q_2, f_1 and f_2 are charges and flavors(e,μ)

BaBar Result at BaBar

$|q/p|-1 = (-0.8 \pm 2.7(\text{stat}) \pm 1.9(\text{syst})) \times 10^{-3}$



Systematic Effects	$\sigma(\|q/p\|)$ $(\times 10^{-3})$
Ch. asym. of non-$B\overline{B}$ bkg	0.6
Ch. asym. in tracking	1.0
Ch. asym. of electrons	1.4
PDF modeling	0.3
Fraction of bkg components	0.2
Δm, τ_{B^0}, $\tau_{B^\pm}$ and $\Delta\Gamma$	0.2
SVT alignment	0.5
Total	1.9

Global fit by HFAG
and conclusions

Average

By Heavy Flavour Averaging Group (HFAG) in 2010

Averaged result of CLEO, BABAR and Belle

$$\mathbf{A_{SL} = -0.0005 \pm 0.0056}$$

$$\mathbf{|q/p| = 1.0002 \pm 0.0028}$$

Averaged result of CLEO, BABAR ,Belle, ALEPH, OPAL and D0 (and assuming $A_{SL}(B_s) = 0$)

$$\mathbf{A_{SL} = -0.0049 \pm 0.0038}$$

$$\mathbf{|q/p| = 1.0025 \pm 0.0019}$$

arXiv:0808.1297v1 [hep-ex]

Used results to average

Exp. & Ref.	Method	Measured $\mathcal{A}_{SL}^d$	Measured $\lvert q/p \rvert_d$
CLEO [103]	partial hadronic rec.	$+0.017 \pm 0.070 \pm 0.014$	
CLEO [104]	dileptons	$+0.013 \pm 0.050 \pm 0.005$	
CLEO [104]	average of above two	$+0.014 \pm 0.041 \pm 0.006$	
BABAR [109]	full hadronic rec.		$1.029 \pm 0.013 \pm 0.011$
BABAR [111]	dileptons		$0.9992 \pm 0.0027 \pm 0.0019$
BABAR [112][p]	part. rec. $D^*\ell\nu$	$-0.0130 \pm 0.0068 \pm 0.0040$	$1.0065 \pm 0.0034 \pm 0.0020$
Belle [113]	dileptons	$-0.0011 \pm 0.0079 \pm 0.0085$	$1.0005 \pm 0.0040 \pm 0.0043$
	Average of 7 above	-0.0047 ± 0.0046 (tot)	1.0024 ± 0.0023 (tot)
OPAL [107]	leptons	$+0.008 \pm 0.028 \pm 0.012$	
OPAL [114]	inclusive (Eq. (49))	$+0.005 \pm 0.055 \pm 0.013$	
ALEPH [108]	leptons	$-0.037 \pm 0.032 \pm 0.007$	
ALEPH [108]	inclusive (Eq. (49))	$+0.016 \pm 0.034 \pm 0.009$	
ALEPH [108]	average of above two	-0.013 ± 0.026 (tot)	
DØ [32]	dimuons	$-0.0092 \pm 0.0044 \pm 0.0032$	
CDF2 [106][p]	dimuons	$+0.0136 \pm 0.0151 \pm 0.0115$	
	Average of 14 above	-0.0058 ± 0.0034 (tot)	1.0030 ± 0.0017 (tot)

[p] Preliminary.

arXiv:0808.1297v1 [hep-ex]

Conclusions

Dilepton charge asymmetry had measured at B-factory and High energy colliders. These averaged value from B-factories is calculated as below

$$|q/p| = 1.0025 \pm 0.0019$$

by HFAG group.

→The result is consistent with SM prediction in the B^0 mixing

BaBar fit fraction

- Event types in fit:

– Signal (both leptons, 81% of B pair events)

– Direct – cascade leptons from the two B mesons (9%)

– Direct – cascade leptons from the same B meson (4%)

– $b \rightarrow \tau \rightarrow (e \text{ or } \mu)$ (3%)

– Charmonium leptons (3%)