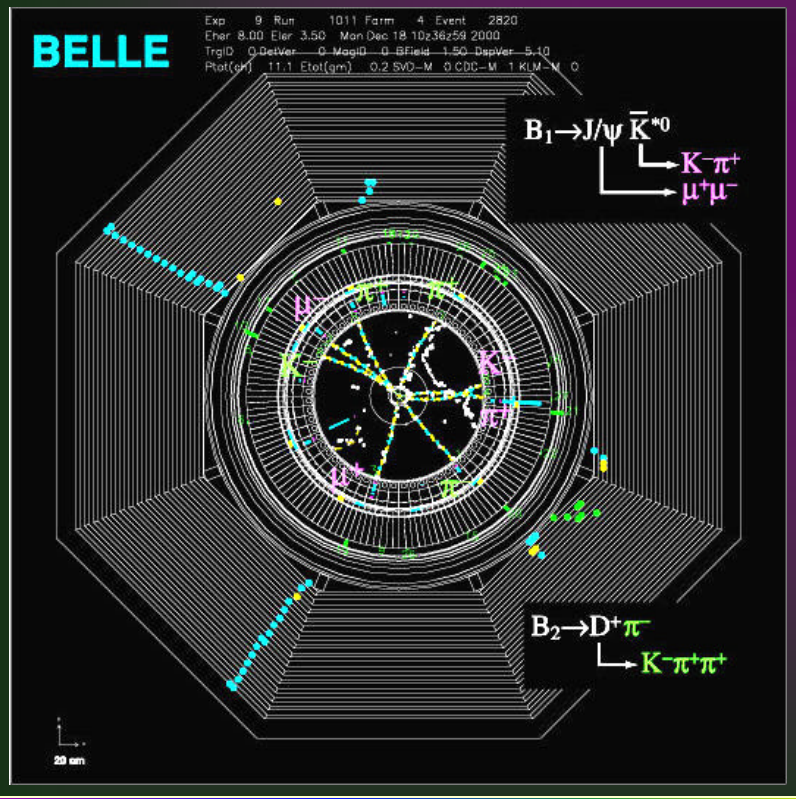
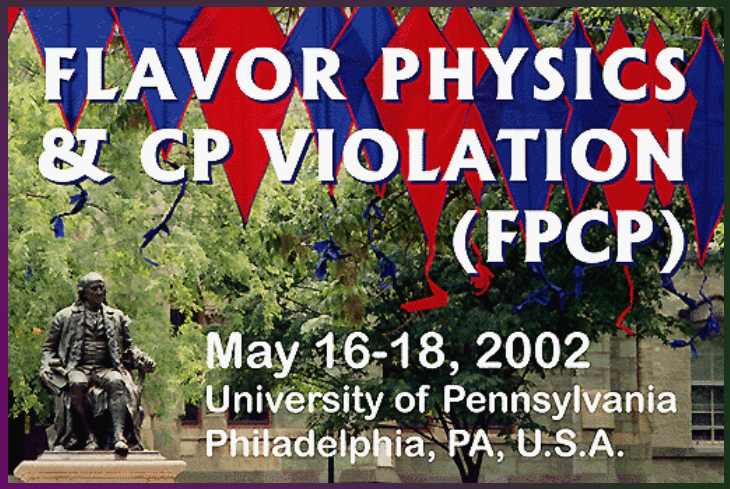
sin2f_1 at *Belle*

Masashi Hazumi (KEK)

for the Belle Collaboration





Outline

- Status of KEKB and Belle
- sin2f_1 Winter '02 Update
- Conclusion

The *Belle* Collaboration

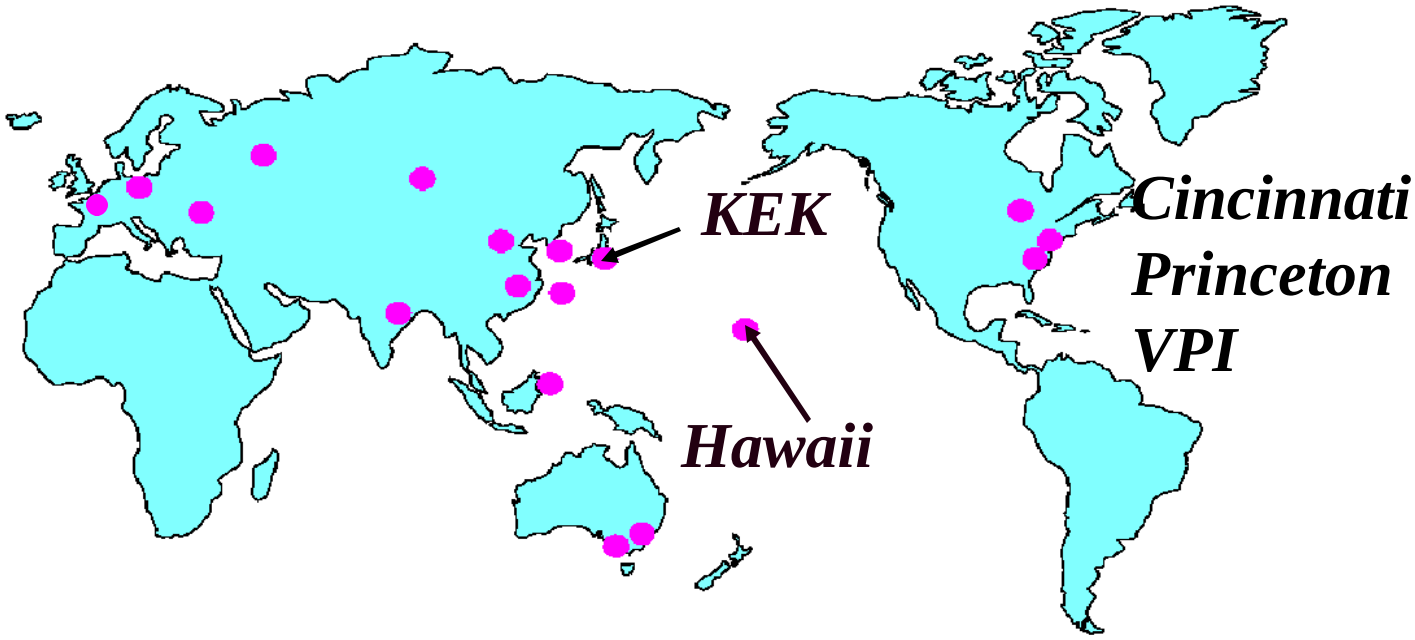
A World-Wide Activity Involving ~50 Institutions

Aomori University
Budker Institute of Nuclear Physics
Chiba University
Chuo University
University of Cincinnati
University of Frankfurt
Gyeongsang National University
University of Hawaii
Hirishima Institute of Technology
IHEP, Beijing
ITEP, Moscow
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
Kyungpook National University
University of Lausanne
Ljubljana
University of Melbourne
Nagoya University
Nara Women's University
National Central University
National Kaoshing Normal University
National Lien-Ho College of Technology
National Taiwan University
Nihon Dental College
Niigata Uniersity
Osaka University
Osaka City University
Panjab University
Peking University
Princeton University
Saga University
University of Science and Technology of China
Seoul National University
Sungkyunkwan University
University of Sydney
Tata University
Toho University
Tohoku University
Tohoku Gakuin University
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculture and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal University
IHEP, Vienna
Virginia Polytechnic Institute and State University
Yokkaichi University
Yonsei University

~300 members

The *Belle* Collaboration

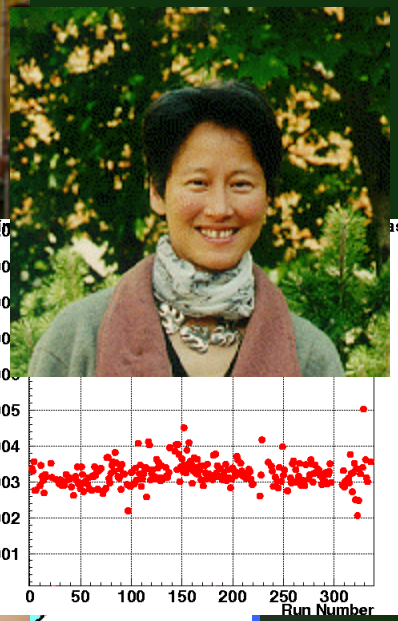
A World-Wide Activity Involving ~50 Institutions

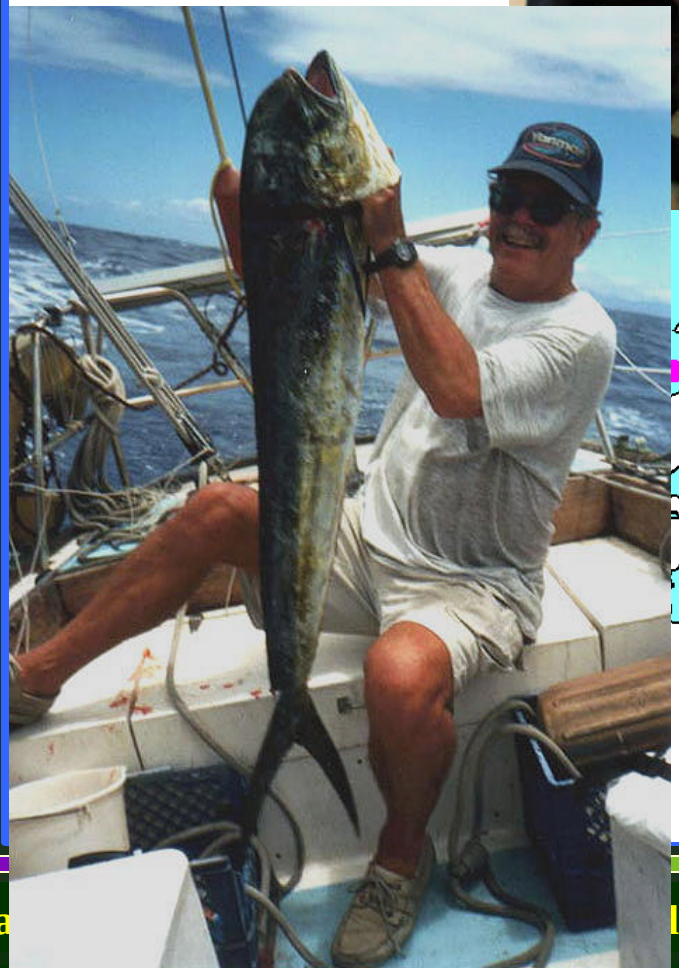


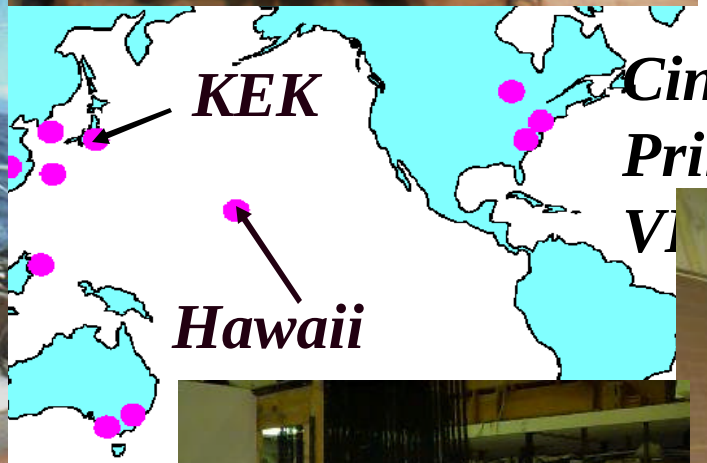
~300 members

The *I*

A World-Wide A



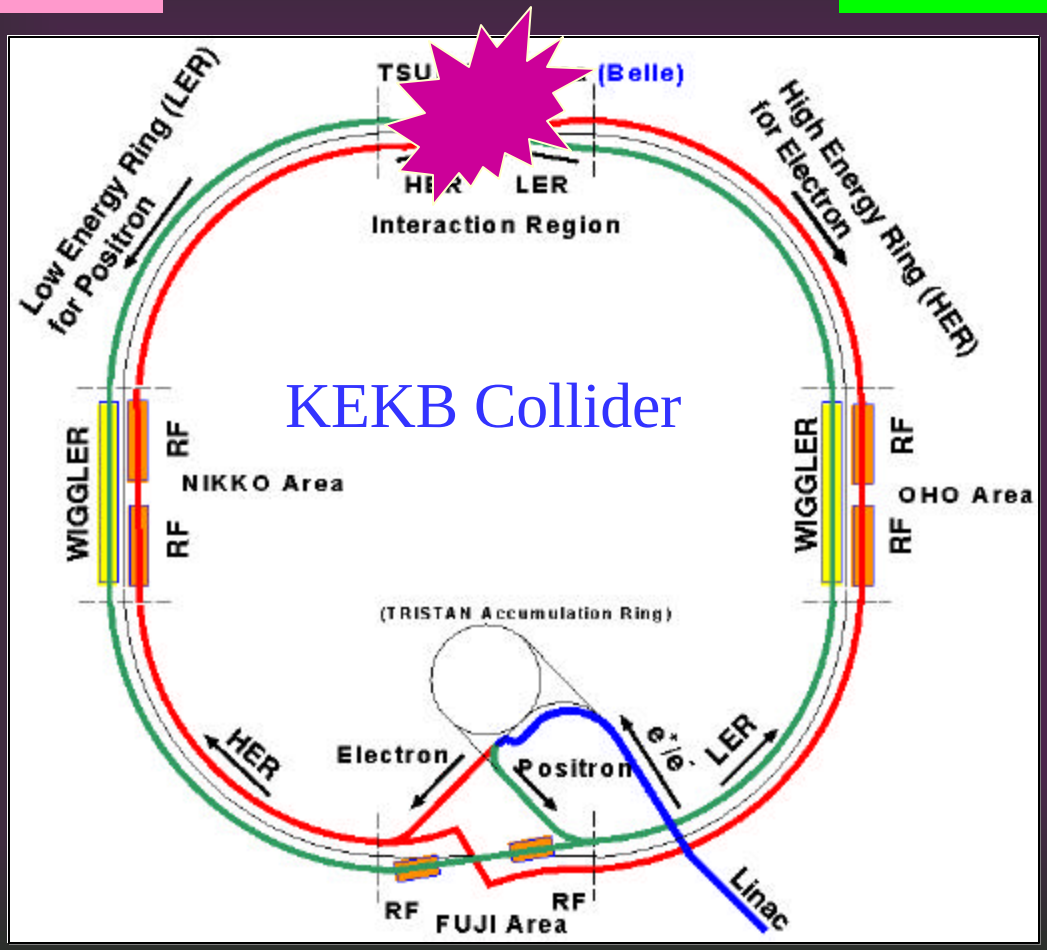




Ma… …lelphia, U…

B Factory at KEK: 1-page Introduction

8GeV electron → ← 3.5GeV positron

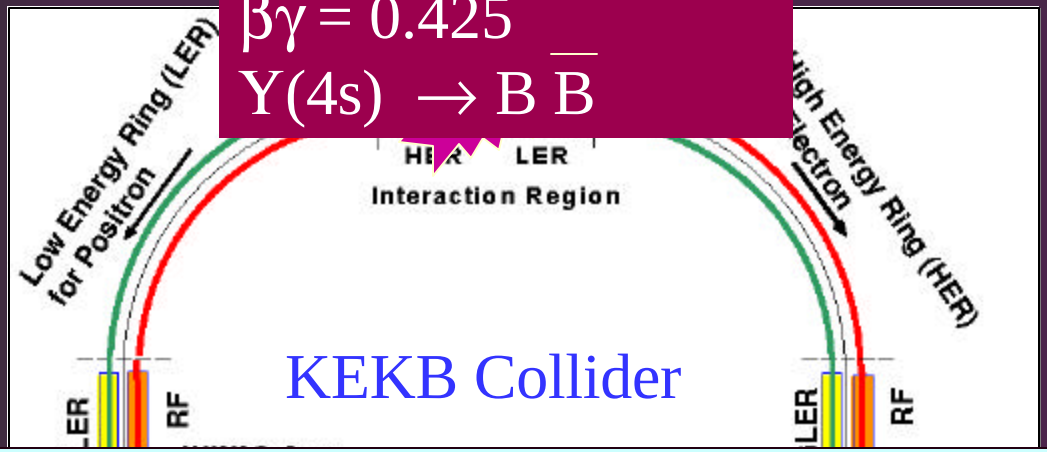


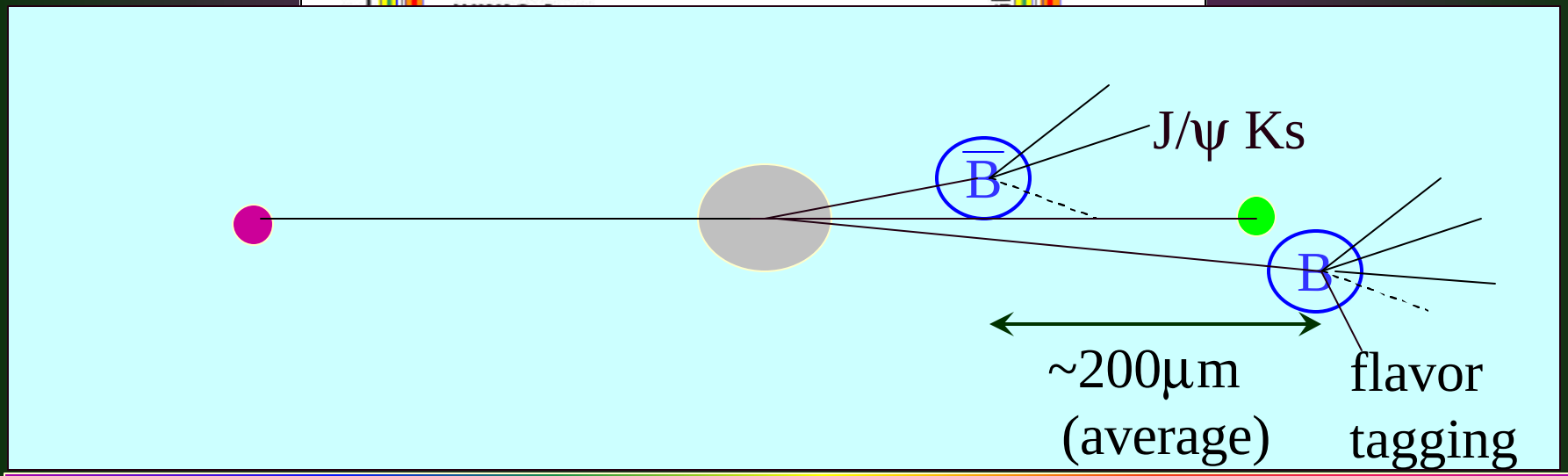
B Factory at KEK: 1-page Introduction

8GeV electron

Υ(4s) (10.58GeV/c^2)
$\beta\gamma = 0.425$
$\Upsilon(4s) \rightarrow B\bar{B}$

3.5GeV positron



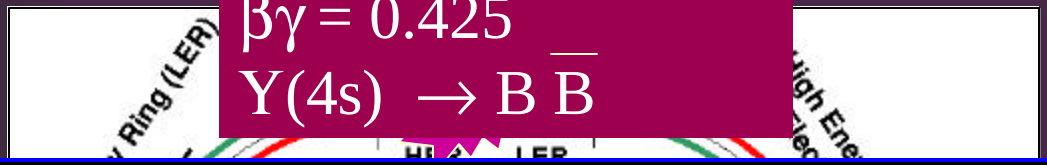


B Factory at KEK: 1-page Introduction

8GeV electron

Y(4s) (10.58GeV/c^2)
$\beta\gamma = 0.425$
$Y(4s) \rightarrow B\,\overline{B}$

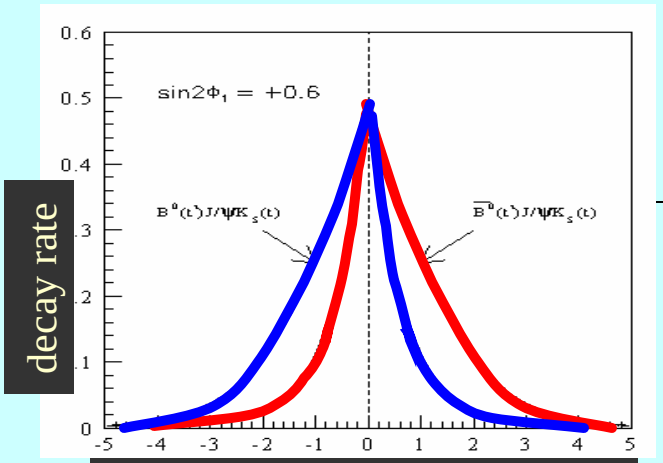
3.5GeV positron

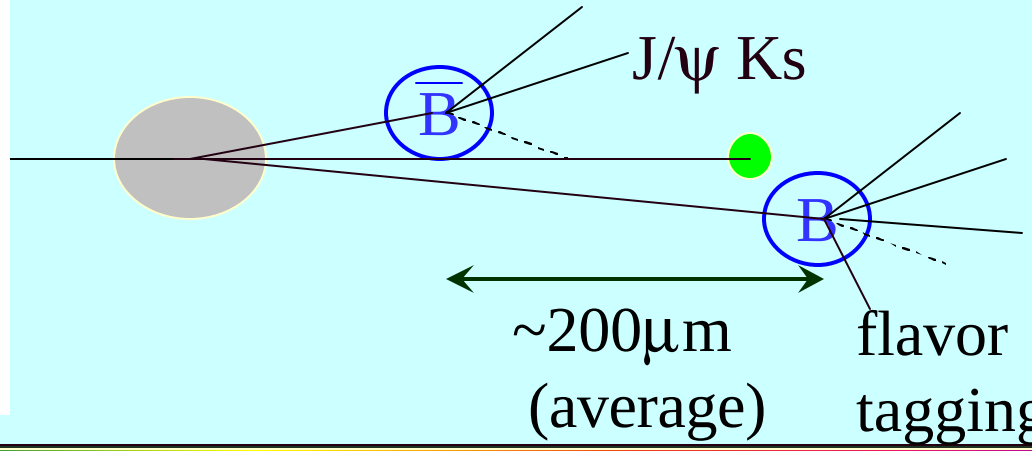


$$\text{Rate} = \exp(-|\Delta t|/\tau_B)/2\tau_B \times \{1-(\xi q)\sin 2\phi_1 \sin(\Delta m \Delta t)\}$$

ξ : CP eigenvalue (e.g. -1 for $J/\psi Ks$)

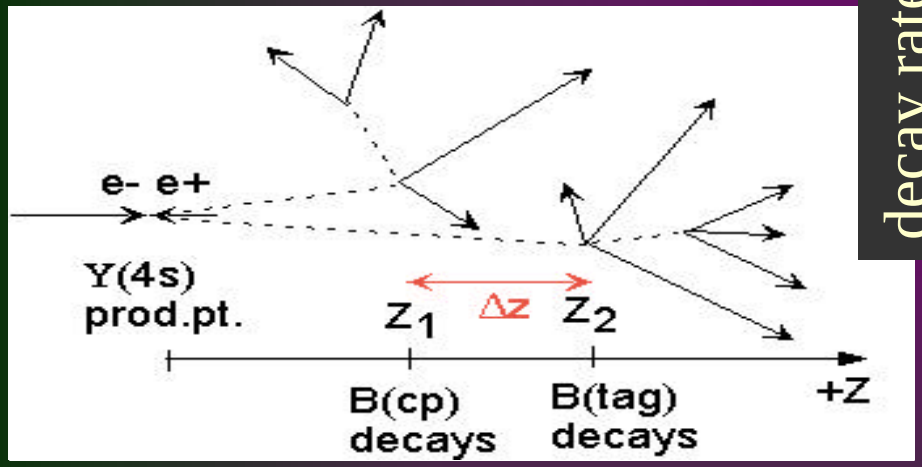
q : Flavor tagging (= +1 for B0-bar(Δt))





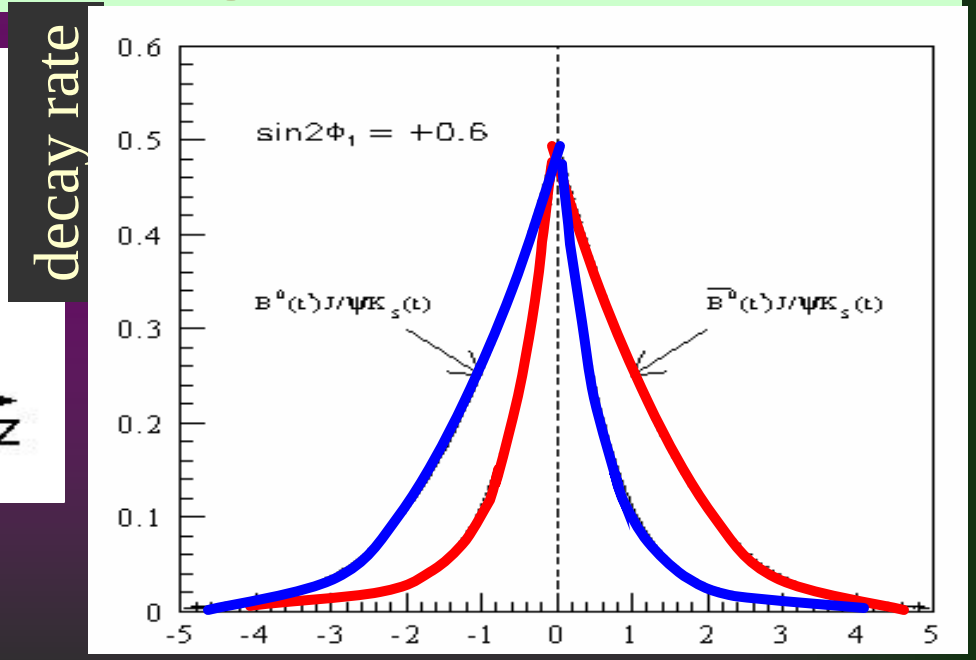
Experimental Challenges

1) Copious B pair production, efficient B reconstruction
2) Efficient and correct flavor tagging
3) Observation of time-dependent CP asymmetry in B decays to a CP eigenstate with good vertex resolution



? z » cß ? ? t

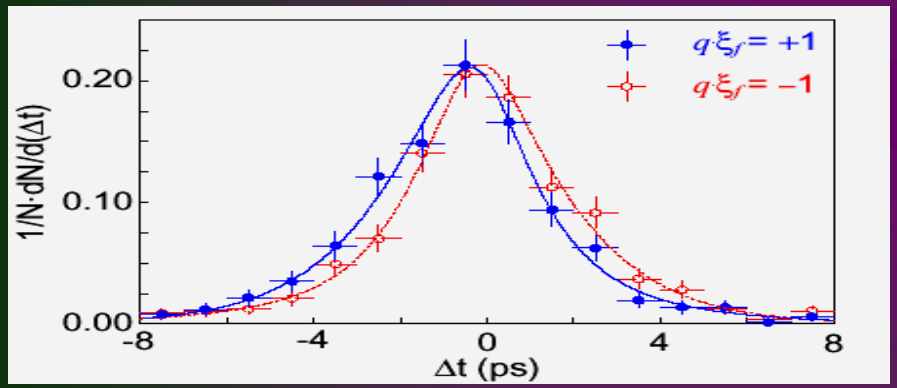
(~200mm at Belle)



July 2001 : the Beginning of New Age

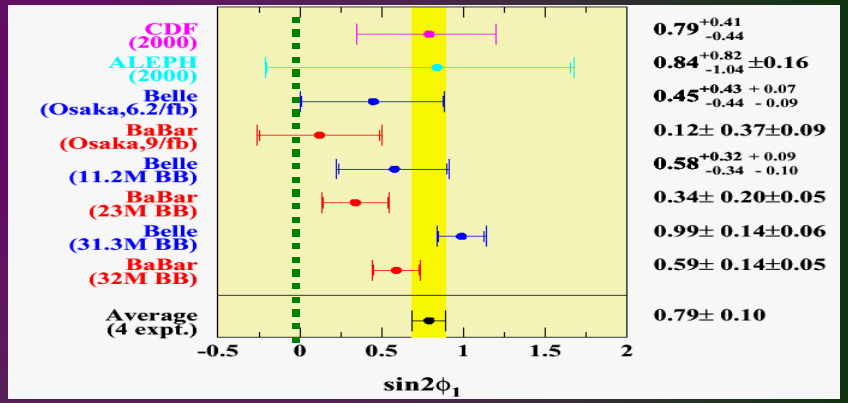
$\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{sys})$ (Belle, July 2001)

29.1fb^{-1} (31.3 million B pairs)
PRL **87**, 091802 (2001)
hep-ex/0202027 (submitted to PRD)



World average (as of July 2001)

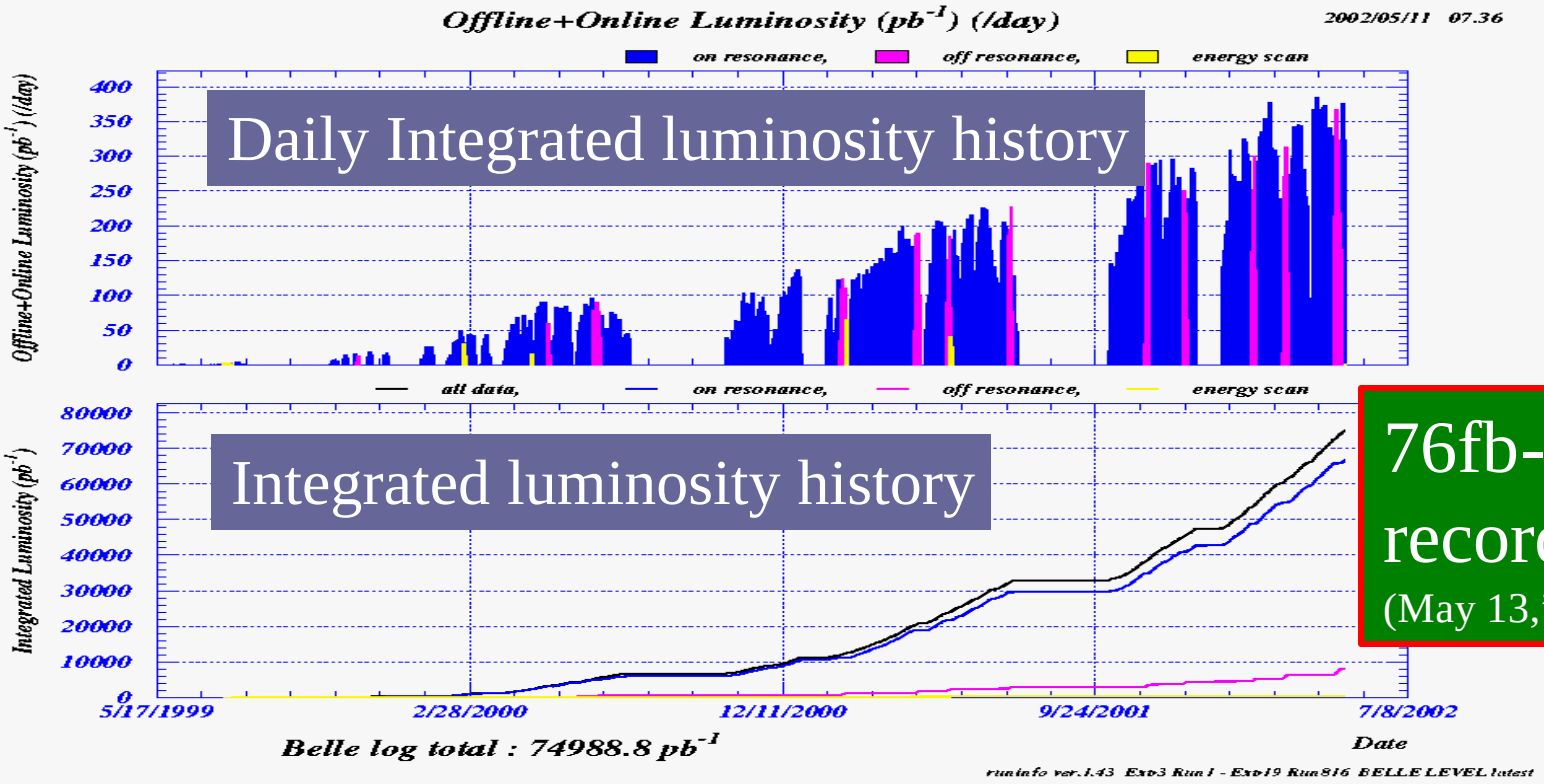
$\sin 2\phi_1 = 0.79 \pm 0.10$



- First CPV observed outside the kaon system
- Strongly support the KM machanism of CPV
  - CP is not an approximate symmetry anymore

KEKB Luminosity: the world's best !

- Peak L $7.25\times10^{33}\ cm^{-2}s^{-1}$ (Mar. 28, '02)
- Daily Integrated L $387\ pb^{-1}/day$ (May. 11, '02)
- Weekly Integrated L $2.14\ fb^{-1}/week$ (Apr. 28, '02)



76fb-1 recorded (May 13,'02)

Belle Detector

Quite stable performance up to now

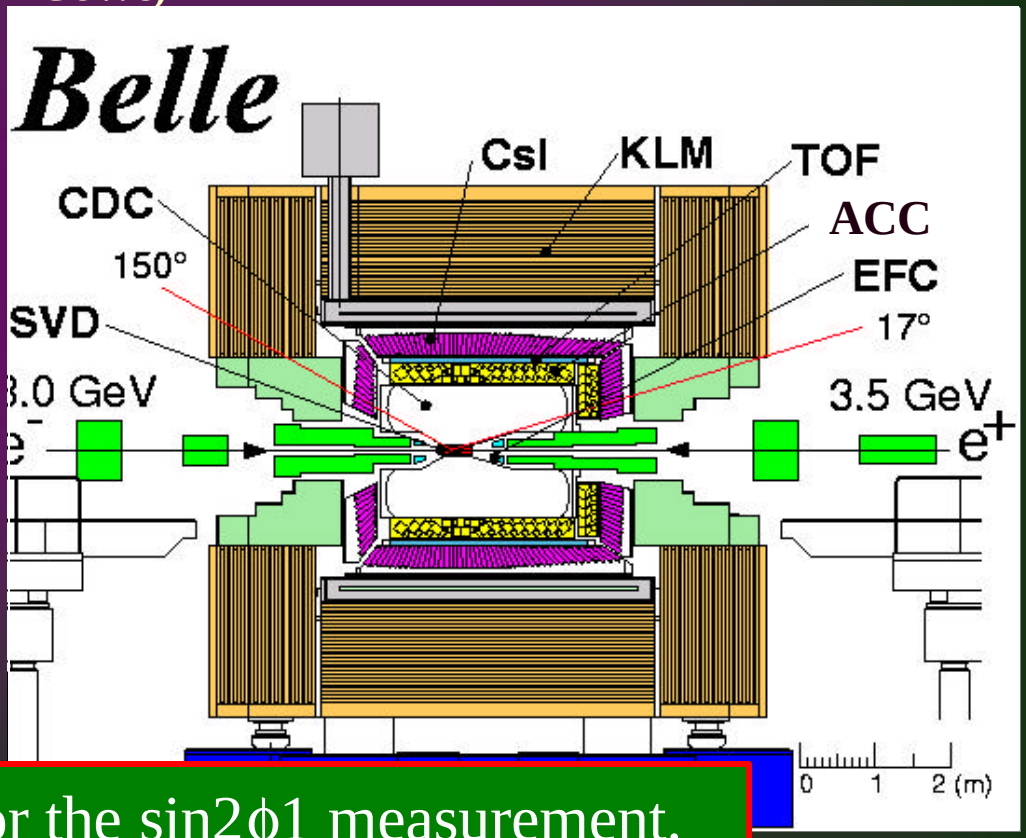
Silicon Vertex Detector (SVD)
Impact parameter resolution
→ 55μm for p=1GeV/c at normal incidence

Central Drift Chamber (CDC)
(σPt/Pt)2 = (0.0019Pt)2 + (0.0034)2 (Pt in GeV/c)2

K/π separation with
dE/dx in CDC (σdE/dx =6.9%)
TOF (σTOF = 95ps)
Aerogel Cerenkov (ACC)
Efficiency = ~90%,
Fake rate = ~6% up to 3.5GeV/c

γ, e± with CsI crystals (ECL)
σE/E ~ 1.8% @ E=1GeV
e± : efficiency > 90%
(~0.3% fake for p > 1GeV/c)

KL and μ± with KLM (RPC chambers)
μ± : efficiency > 90%
(<2% fake at p > 1GeV/c)



All components are importantfor the sin2φ1 measurement.

nce up to now

Silicon Vertex Detector (SVD)

Impact parameter resolution

→ 55mm for p=1GeV/c at no

Central Drift Chamber (CDC)

(s Pt/Pt)2 = (0.0019Pt)2 + (0.0

K/p separation with

dE/dx in CDC (s dE/dx =6.9%)

TOF (s TOF = 95ps)

Aerogel Cerenkov (**ACC**)

Efficiency = ~90%,

Fake rate = ~6% up to 3.5GeV/c

g, e± with CsI crystals (ECL)

s E/E ~ 1.8% @ E=1GeV

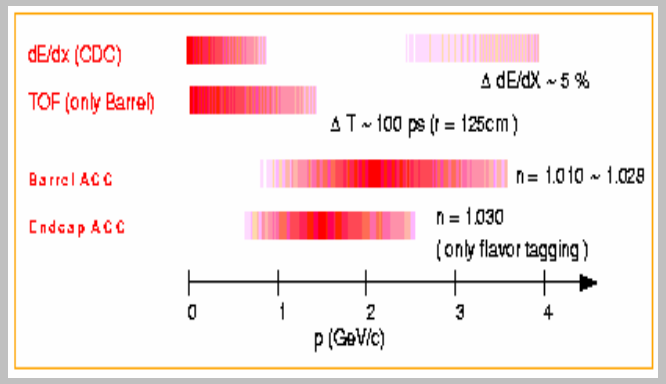
e± : efficiency > 90%

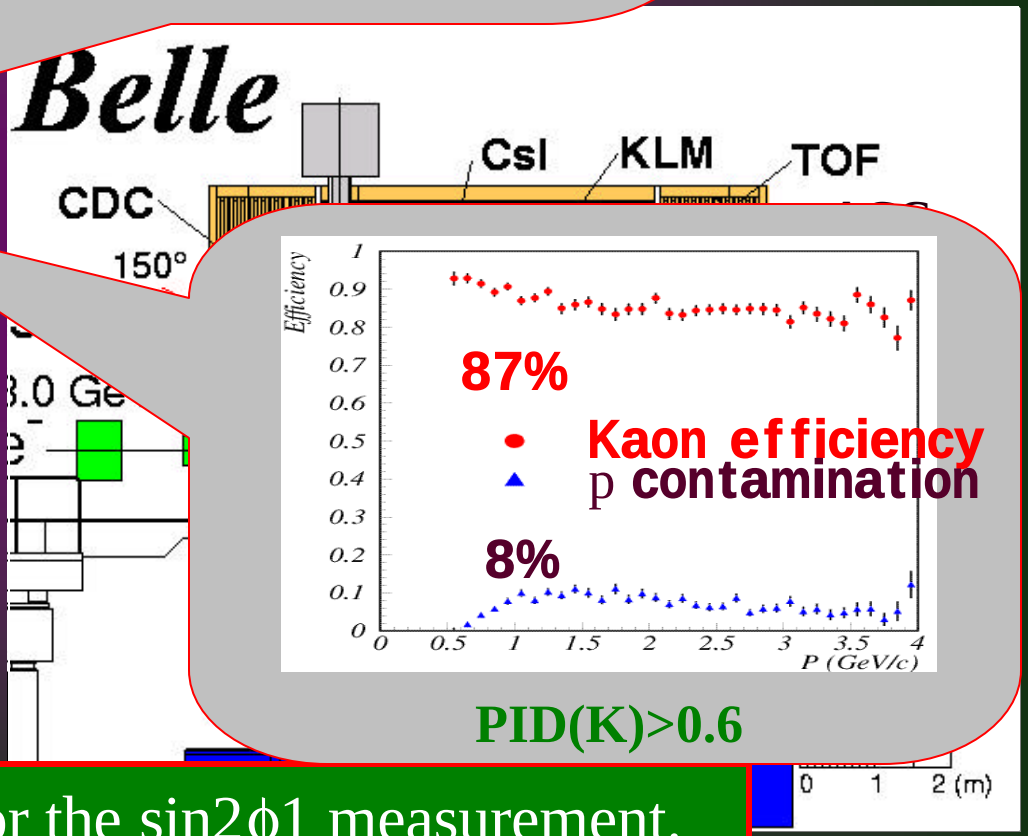
(~0.3% fake for p > 1GeV/c)

KL and m± with KLM (RPC chambers)

m± : efficiency > 90%

(<2% fake at p > 1GeV/c)

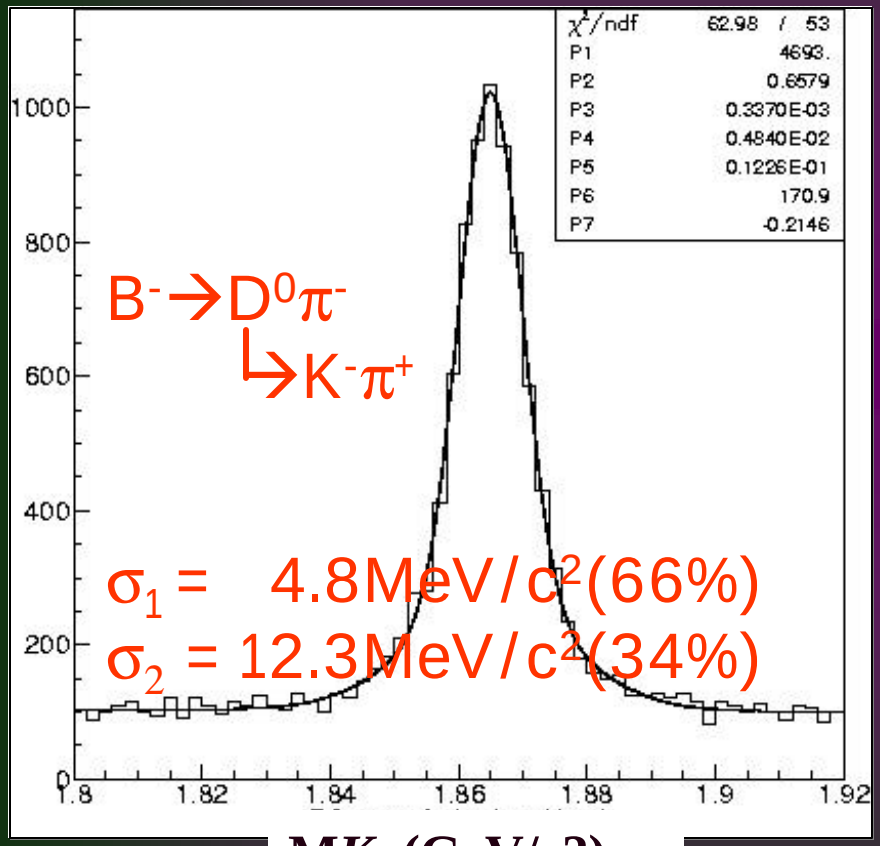


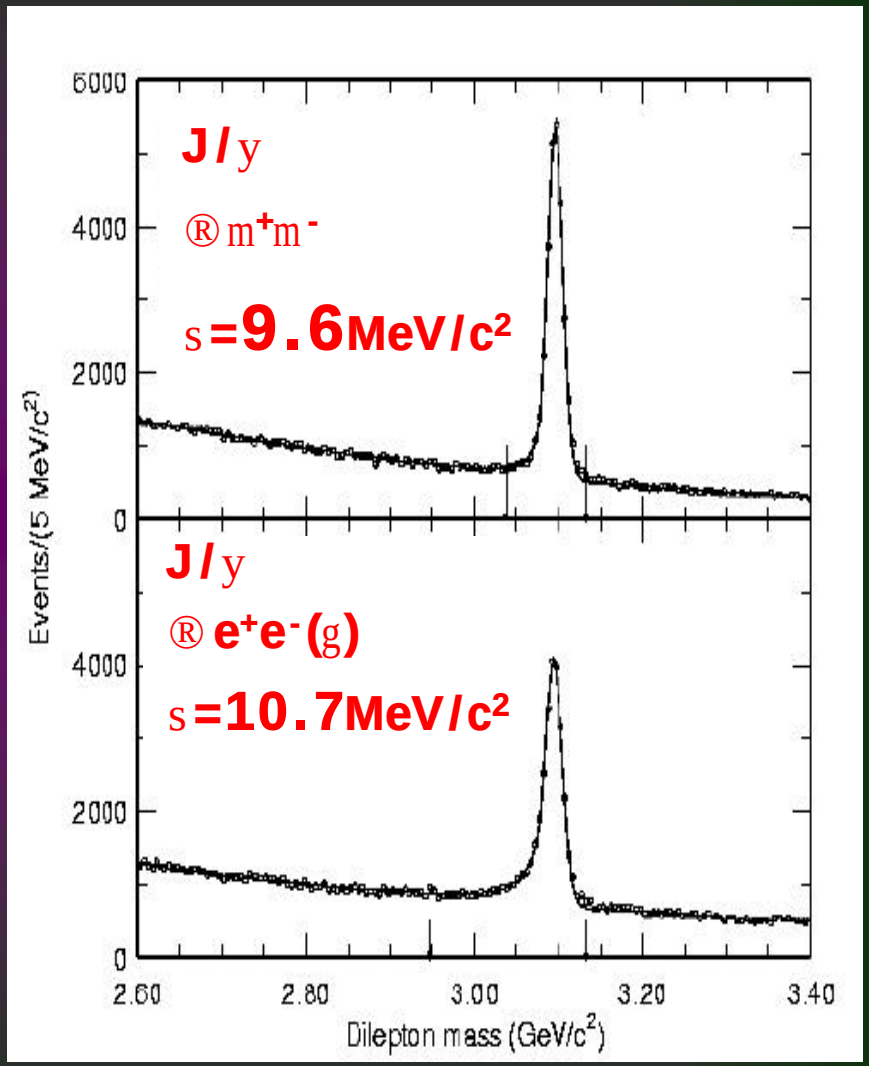


PID(K)>0.6

All components are importantfor the sin2ϕ1 measurement.

Mass Resolutions (1)



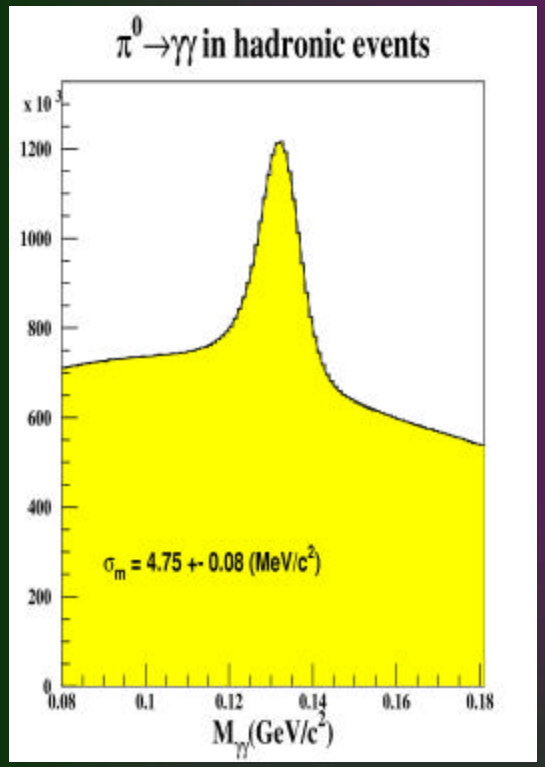


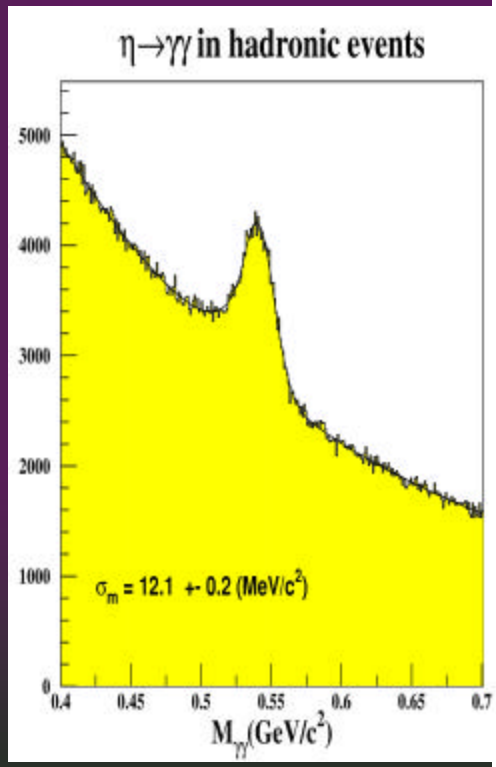
Mass Resolutions (2)

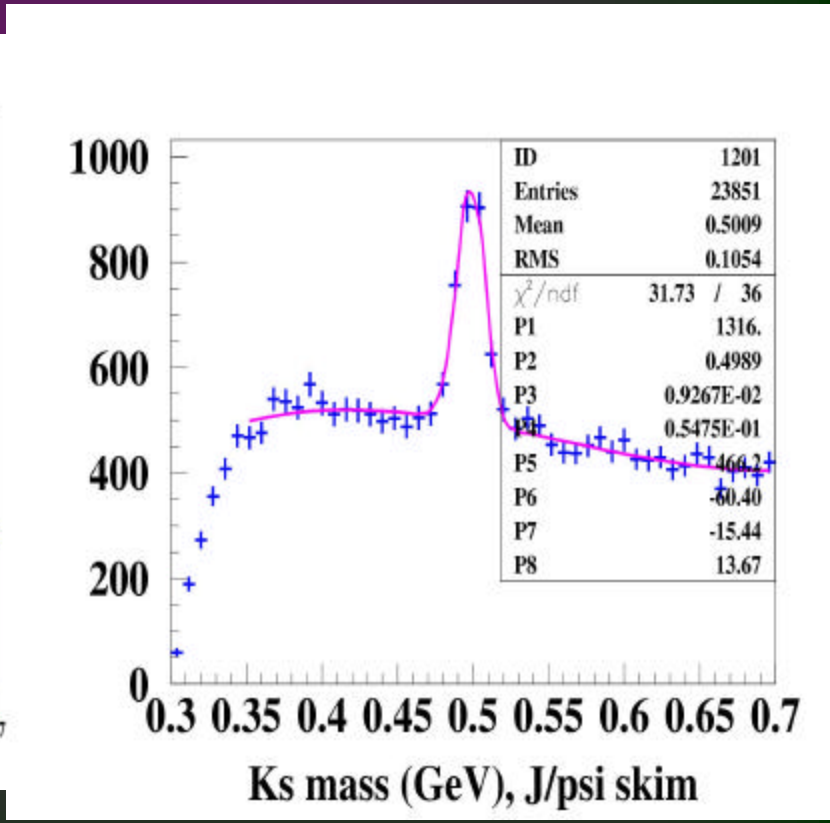
$\pi^0 \to \gamma\gamma$
$\sigma = 4.8 \text{MeV}/c^2$

$\eta \to \gamma\gamma$
$\sigma = 12.1 \text{MeV}/c^2$

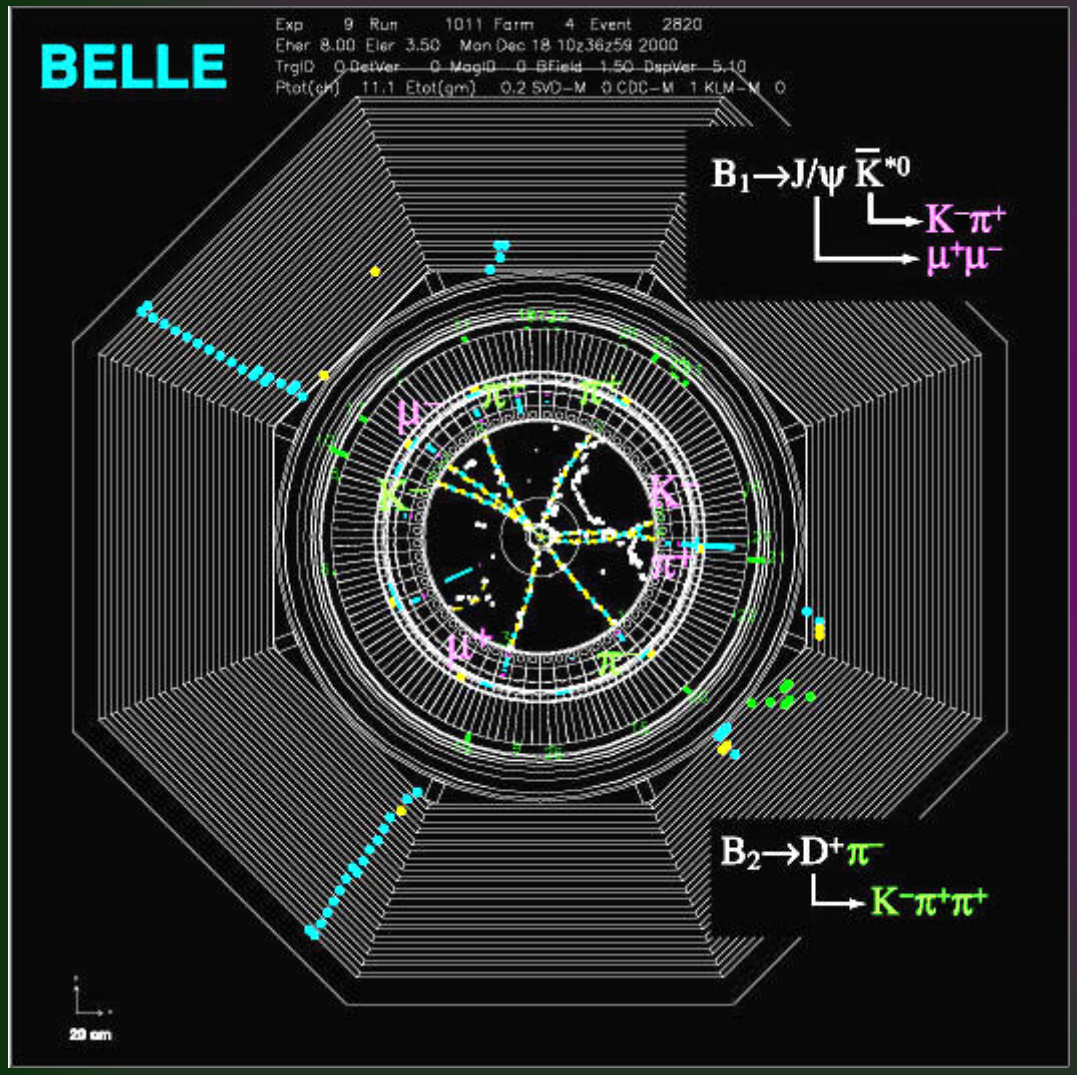
$Ks \to \pi 0 \pi 0 \to \gamma\gamma\gamma\gamma$
$\sigma = 12.1 \text{MeV}/c^2$

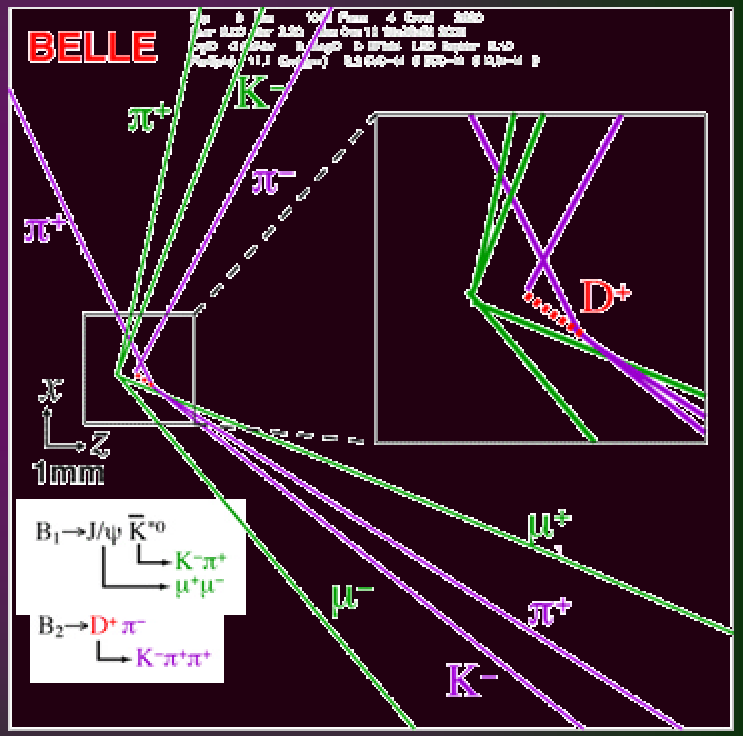






Fully-reconstructed Event Example

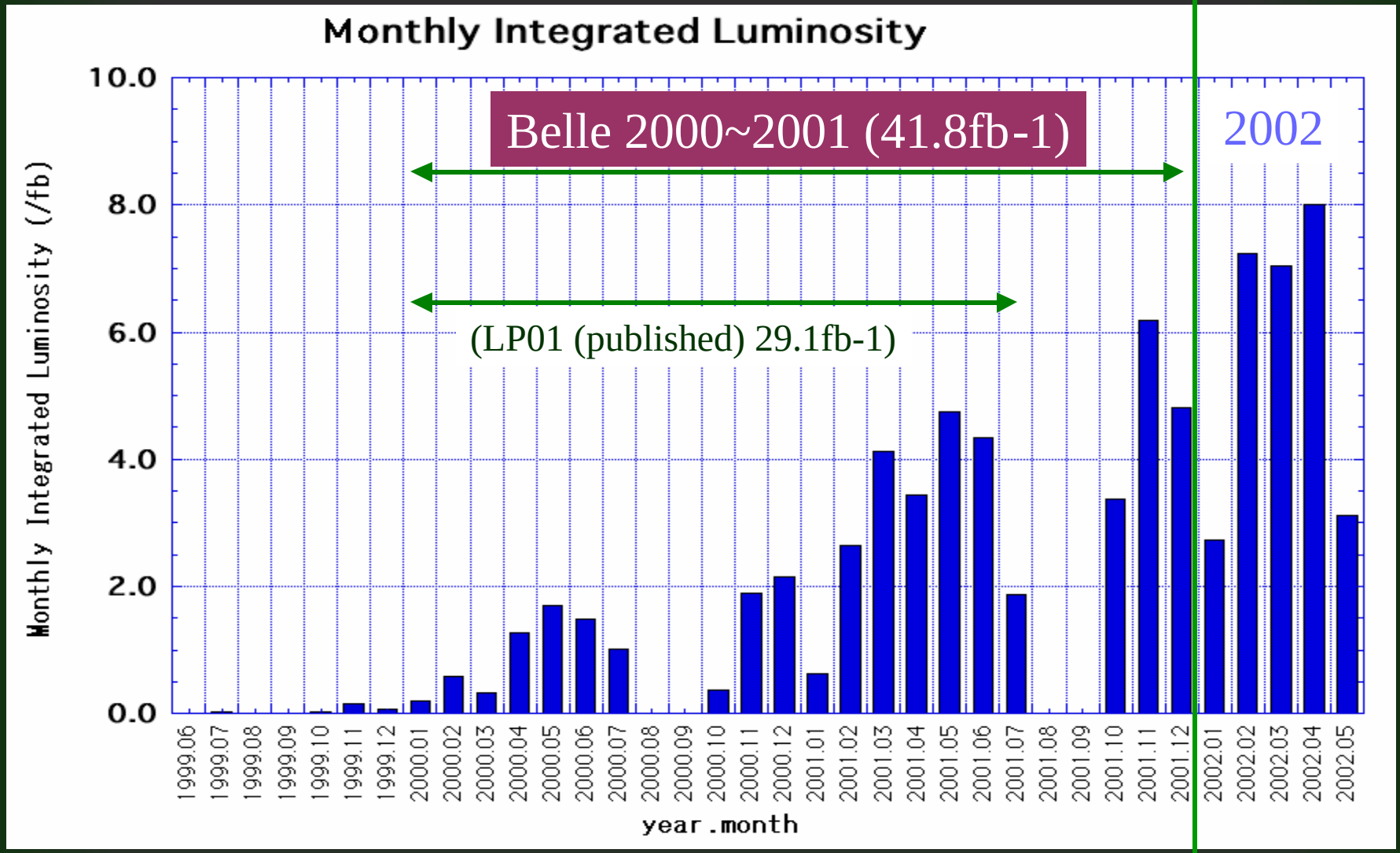




sin2ϕ_1 Winter '02 Update

[Major update → Summer 2002 (~90fb-1)]

Data Set


Monthly Integrated Luminosity
Belle 2000~2001 (41.8fb-1)
2002
(LP01 (published) 29.1fb-1)
Monthly Integrated Luminosity (/fb)
10.0
8.0
6.0
4.0
2.0
0.0
1999.06
1999.07
1999.08
1999.09
1999.10
1999.11
1999.12
2000.01
2000.02
2000.03
2000.04
2000.05
2000.06
2000.07
2000.08
2000.09
2000.10
2000.11
2000.12
2001.01
2001.02
2001.03
2001.04
2001.05
2001.06
2001.07
2001.08
2001.09
2001.10
2001.11
2001.12
2002.01
2002.02
2002.03
2002.04
2002.05
year.month

Reconstruction of CP Eigenstates

Mode	# of Ev.	Purity
$J/\psi K_S(\pi^+\pi^-)$	**636**	**0.95**
$J/\psi K_S(\pi^0\pi^0)$	**102**	**0.80**
$\psi(2S)(l^+l^-)K_S$	**49**	**0.95**
$\psi(2S)(J/\psi\,\pi^+\pi^-)K_S$	**57**	**0.93**
$\chi_{c1}(J/\psi\,\gamma)K_S$	**34**	**0.93**
$\eta_c(K_SK^+\pi^-)K_S$	**39**	**0.72**
$\eta_c(K^+K^-\pi^0)K_S$	**33**	**0.73**
$J/\psi K^{*0}(K_S\pi^0)$	**55**	**0.89**
$J/\psi K_L$	**767**	**0.60**
Total	1772	

CP-odd ($\xi = -1$)

even/odd mix.

CP-even ($\xi = +1$)

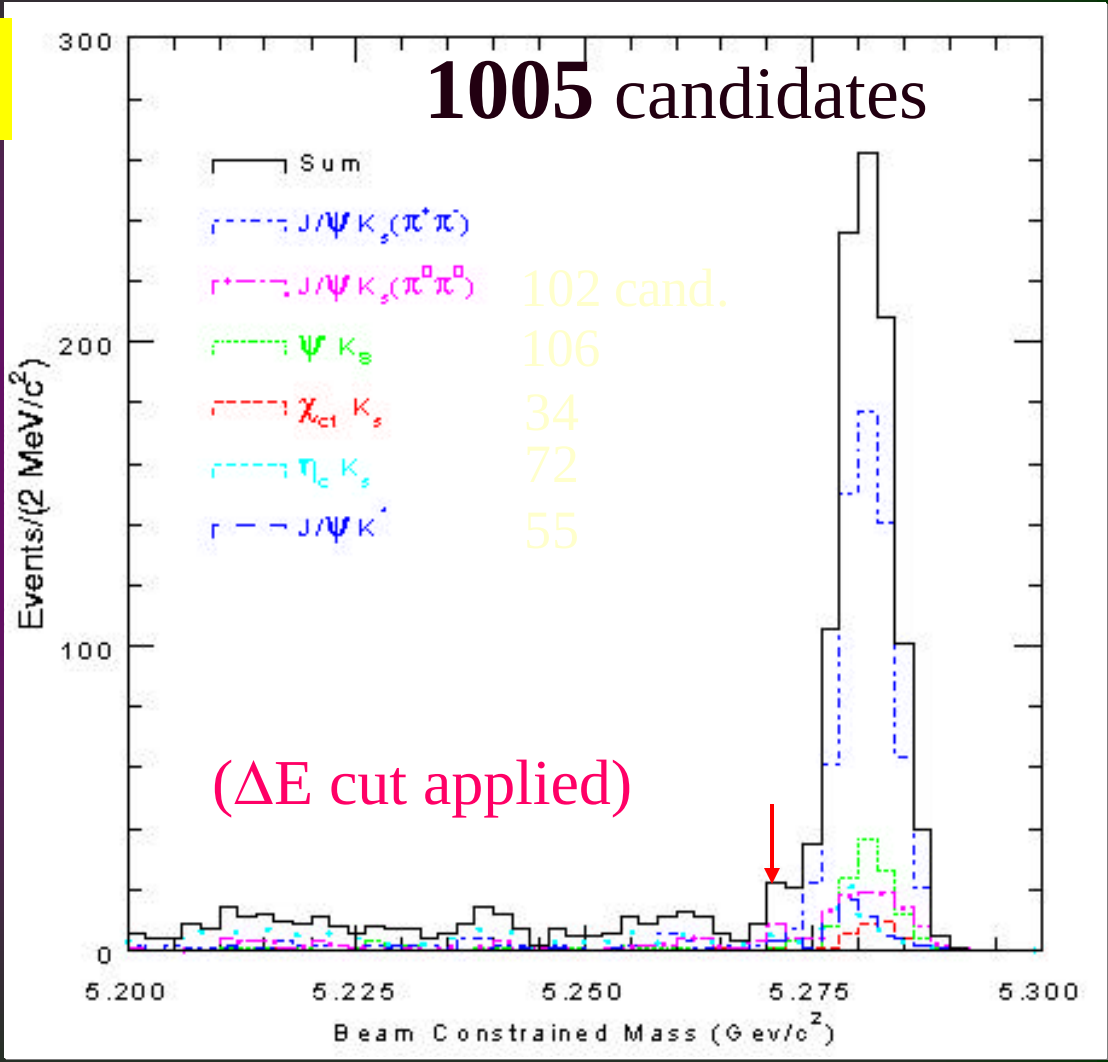
All Modes (except B^0 ® J/ψ K_L)

B^0 ® J/y Ks($\rightarrow\pi^+\pi^-$)

636 candidates
~31 background
(Purity = 95%)

B^0 ® other modes

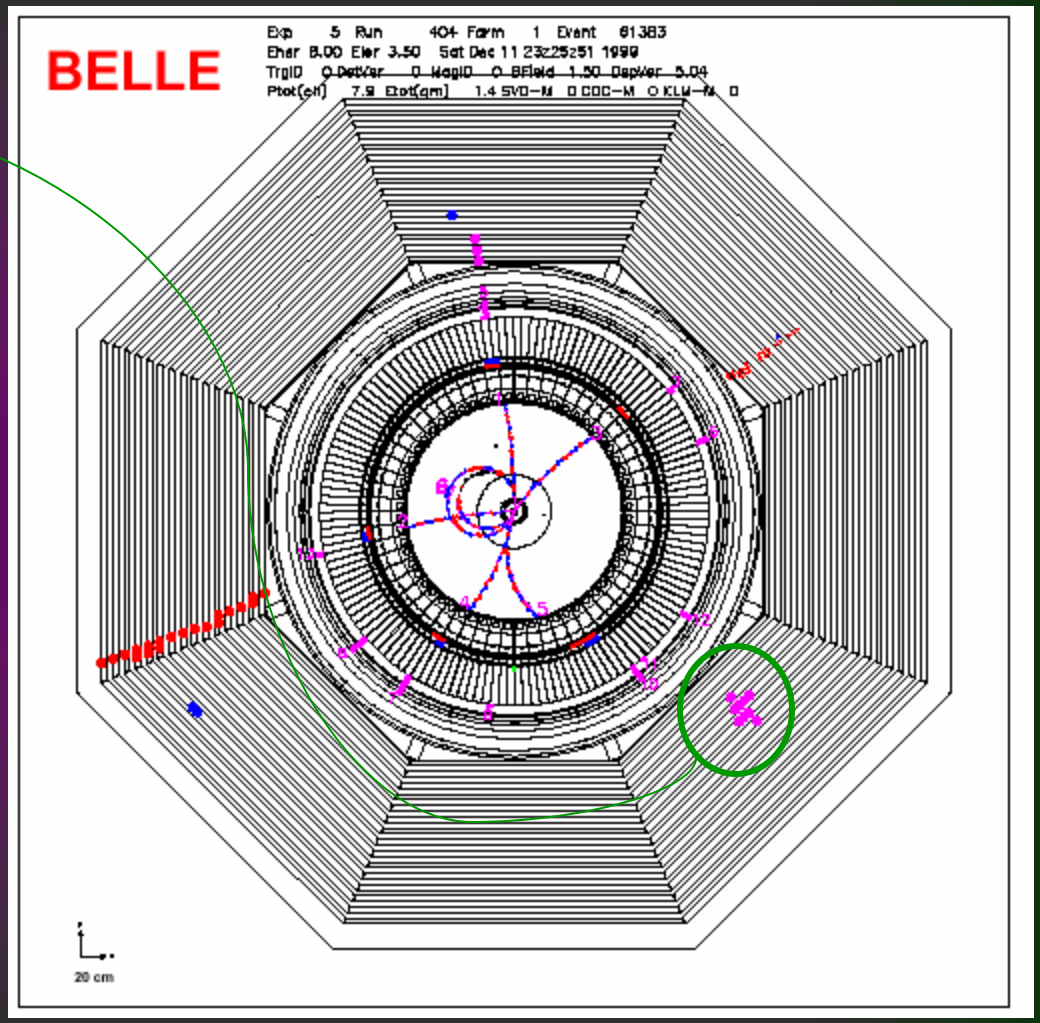
369 candidates
~59 background
(Purity = 84%)



B^0 ® J/y K_L

1) J/y ® l^+l^- + K_L
2) Assume B→J/y K_L: compute $\vec{P}_{KL}$
3) Remove reconstructed B ® J/y K, J/y K*, …
4) Cut on a likelihood based on kinematical and shape quantities
5) Plot $P^*_B = |\vec{P}_{J/y} + \vec{P}_{KL}|$

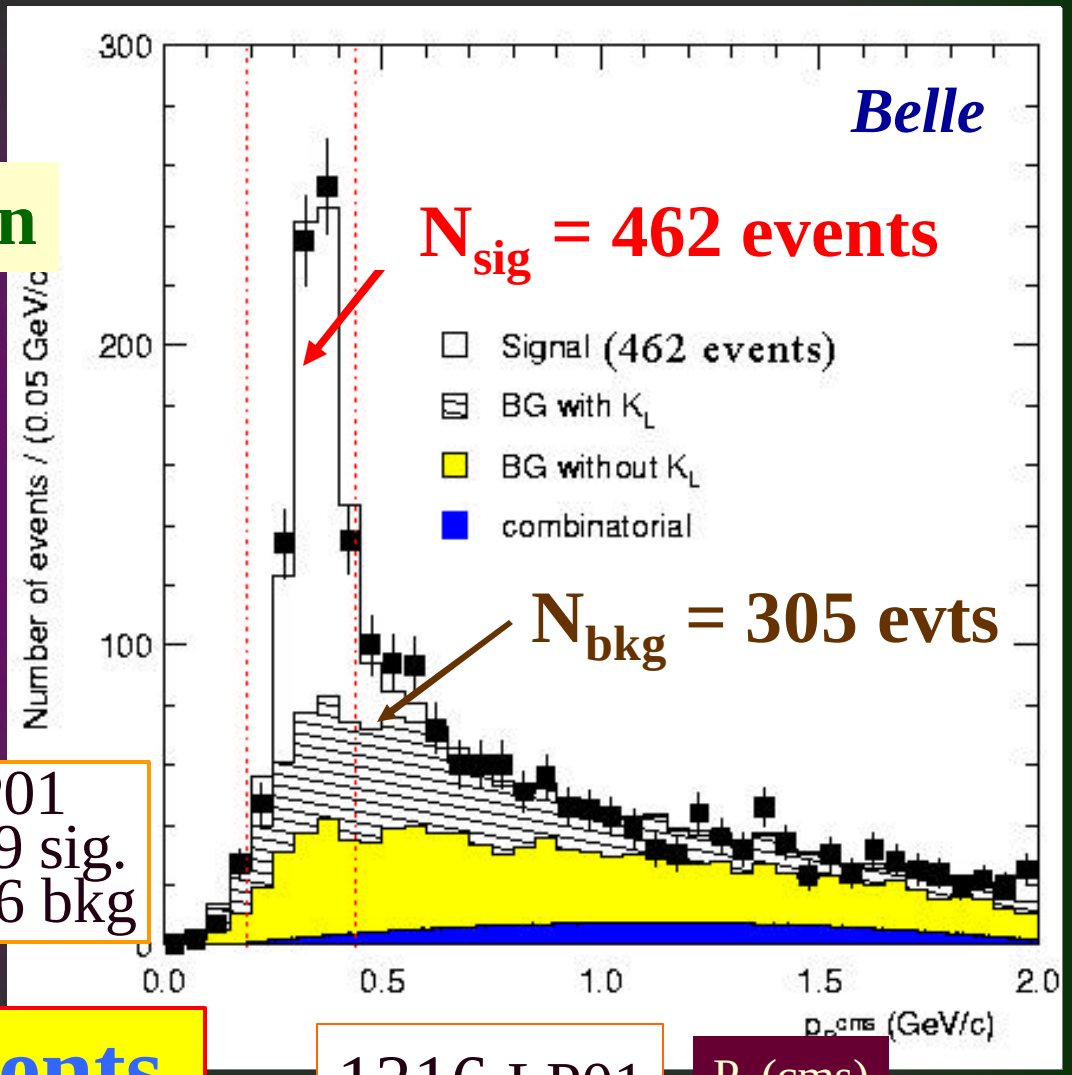
K_L direction + 2-body decay kinematics



$B^0 \to J/\psi K_L$

$$P_B^* = \left| \vec{P}^*_{J/\psi} + \vec{P}^*_{KL} \right|$$

run-dep. E_{beam} correction



$B^0 \to J/\psi K_L$

767 total events
462 signal
(Purity = 60%)

← LP01
569 sig.
346 bkg

Total 1772 CP events

← 1316 LP01

P_B(cms)

Flavor Tagging (no change from LP01)

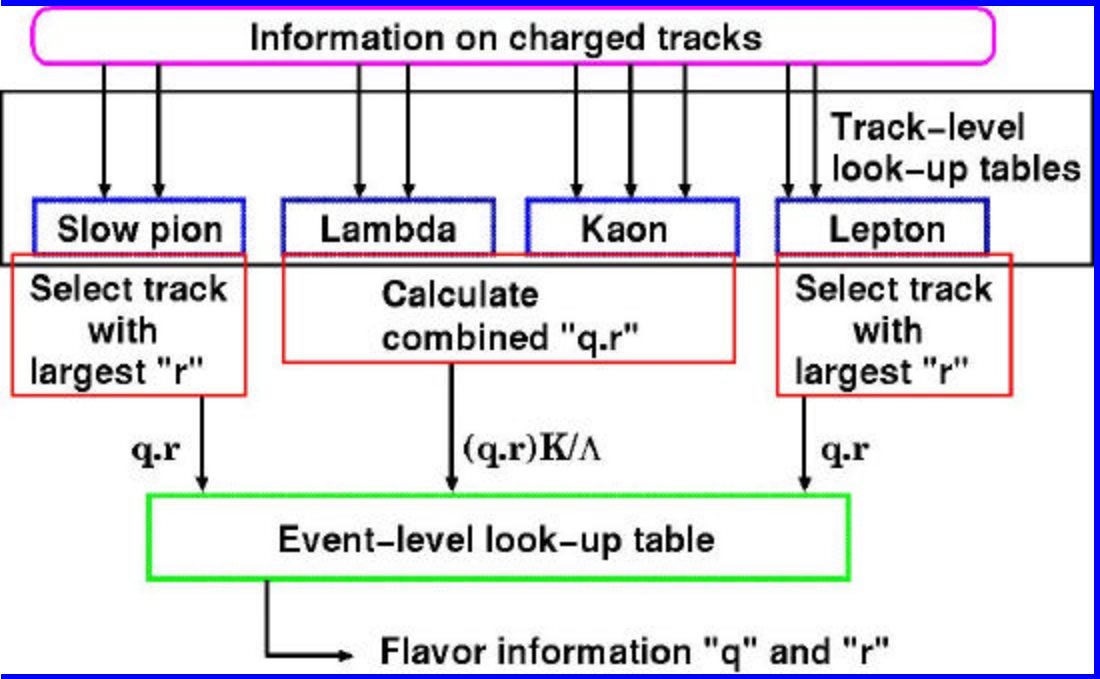
Use *inclusive* flavor-specific properties:

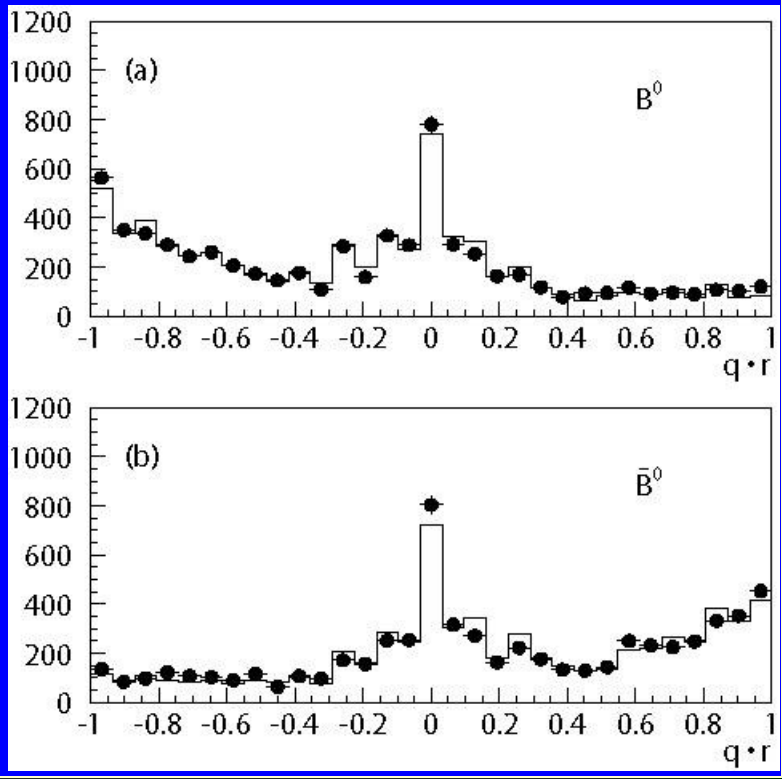
- ***Inclusive Leptons:***
  - ***high-p*** l^- $\quad b \to c\, l^-\, n$
  - ***intermed-p*** l^+ $\quad \hookrightarrow s\, l^+\, n$
- ***Inclusive Hadrons:***
  - ***high-p*** p^+ $\quad B^0 \to D^{(*)-}\, p^+,\ D^{(*)-}\, r^+$, ***etc.***
  - ***intermed-p*** K^+ $\quad \hookrightarrow K^+\, X,$ $\quad \hookrightarrow p^+ p^0$
  - ***low-p*** p^- $\quad \hookrightarrow \bar{D}^0\, p^-$

Also include *correlations*

Belle Flavor Tagging Method

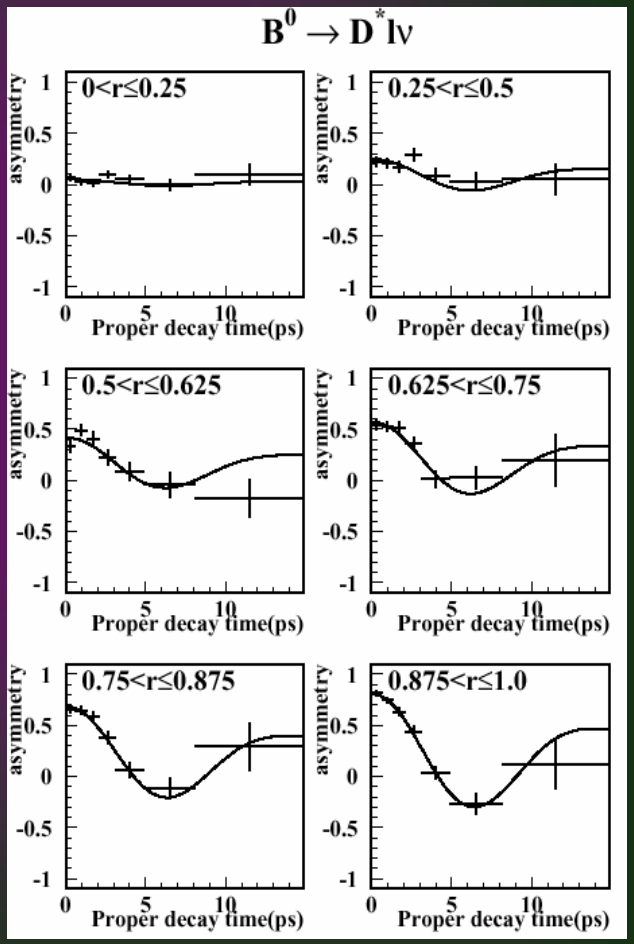
Look-up tables





Wrong-tag Fraction Determination

Wrong tag fractions in 6 tagging categories



Flavor specific decays + Tagging

$B^0 \to D^* l\nu$, $D^{(*)}\pi/\rho$ ($\to$mixing)

$$\text{Asym} = \frac{\text{OF} - \text{SF}}{\text{OF} + \text{SF}}$$

OF = Opposite Flavor

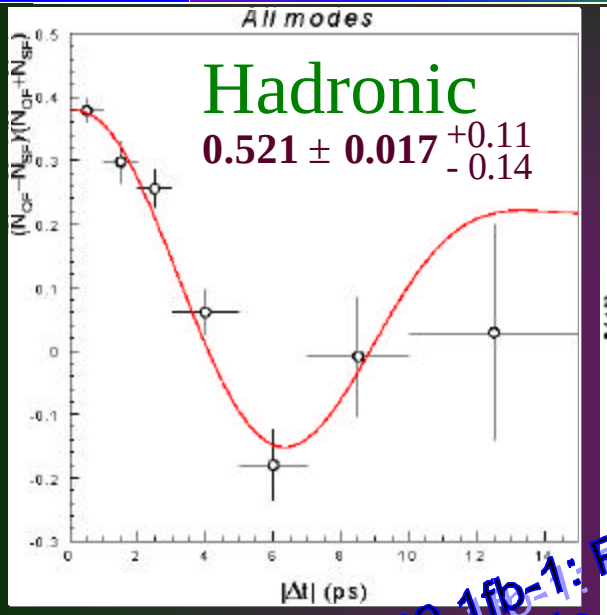
SF = Same Flavor (i.e. oscillated)

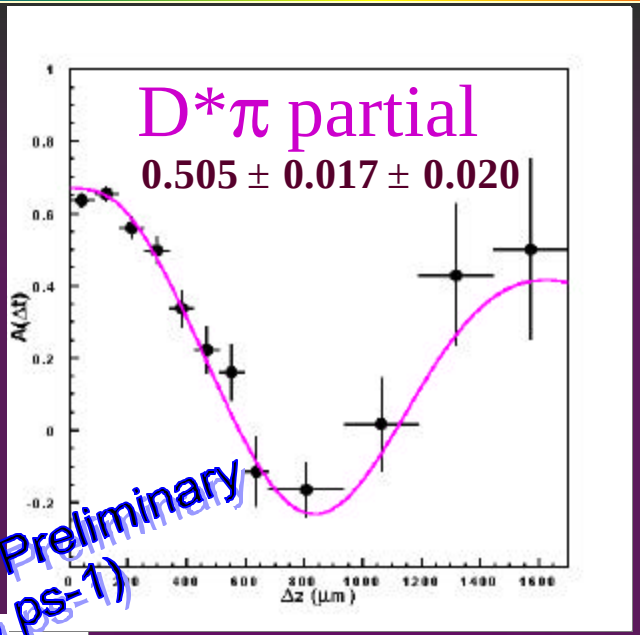
determined by data

Efficiency > 99.5%

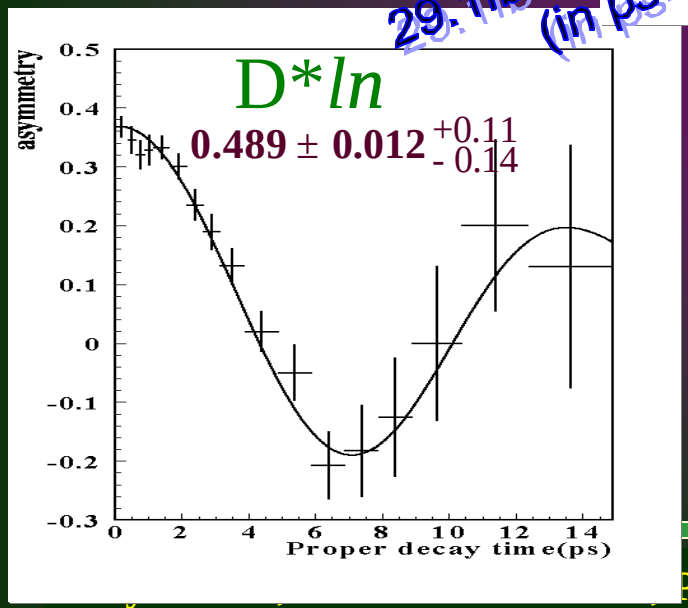
$\varepsilon_{\text{effective}} = 27.0 \pm 1.2\%$

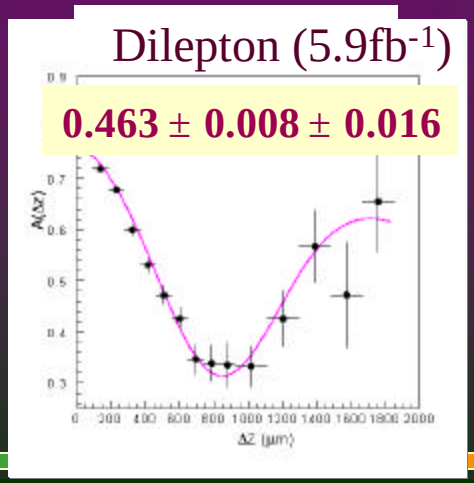
Related topic: Δm_d (4 methods)

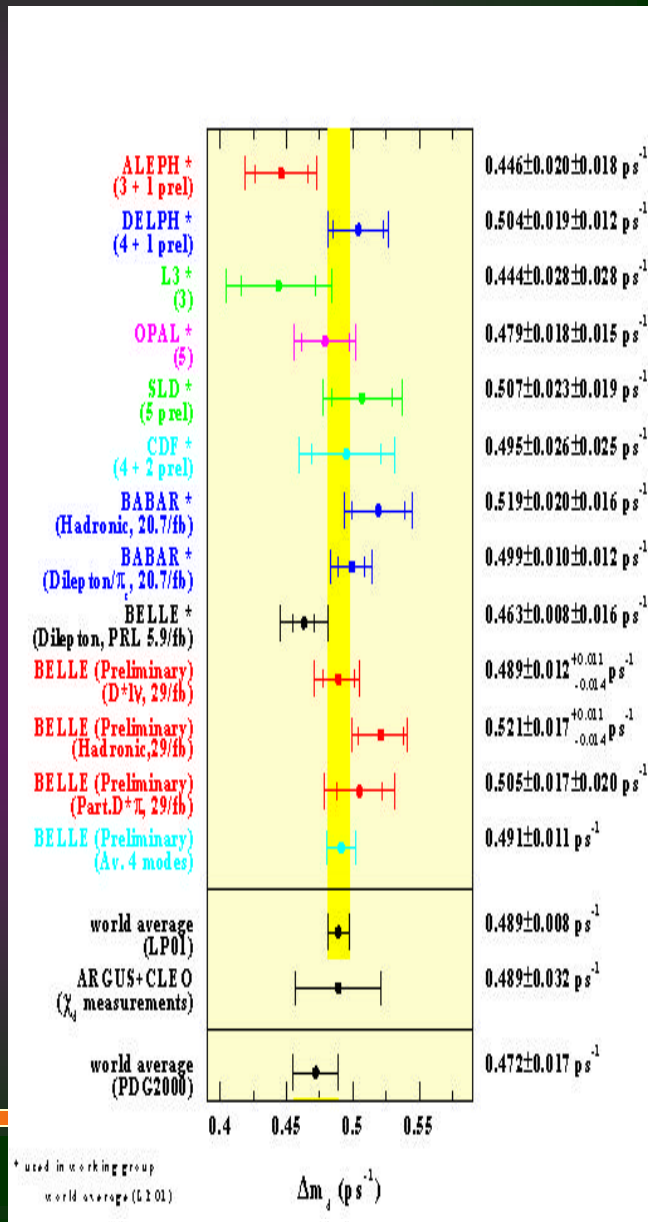




29.1fb-1: Preliminary (in ps-1)







Philadelphia, U.S.A.

Event-by-event Likelihood

double Gaussian

$$L_i = (1-f_{ol})\{\int((1-f_{bk})P_{sig}(\Delta t')\otimes R_{sig}(\Delta t-\Delta t')$$

$$+ f_{bk}P_{bk}(\Delta t')\otimes R_{bk}(\Delta t-\Delta t'))d\Delta t'\} + f_{ol}P_{ol}(\Delta t)$$

Taken from data

$$P_{sig}(\Delta t) = \frac{1}{2\tau_B} e^{-|\Delta t|/\tau_B}(1 - x_f q(1-2w))$$

$$\times \sin(2\phi_1)\sin(\Delta m_d \Delta t))$$

$$P_{bk}(\Delta t) = f_t e^{-|\Delta t|/\tau_{bkg}}/2\tau_{bkg} + (1-f_t)d(\Delta t)$$

Improved Resolution Functions

- Separate response functions for “vtx with 1-track + IP constraint” and other
- Outlier treatment
- Already adopted for the B lifetime analysis

$$\mathbf{Pdf(\Delta t) = P_{sig} \otimes R_{sig} + P_{BG} + P_{OL}}$$

$$\mathbf{R_{sig} = R_{det} \otimes R_{NP} \otimes R_{Kin}}$$

More sensitive to R(Δt)

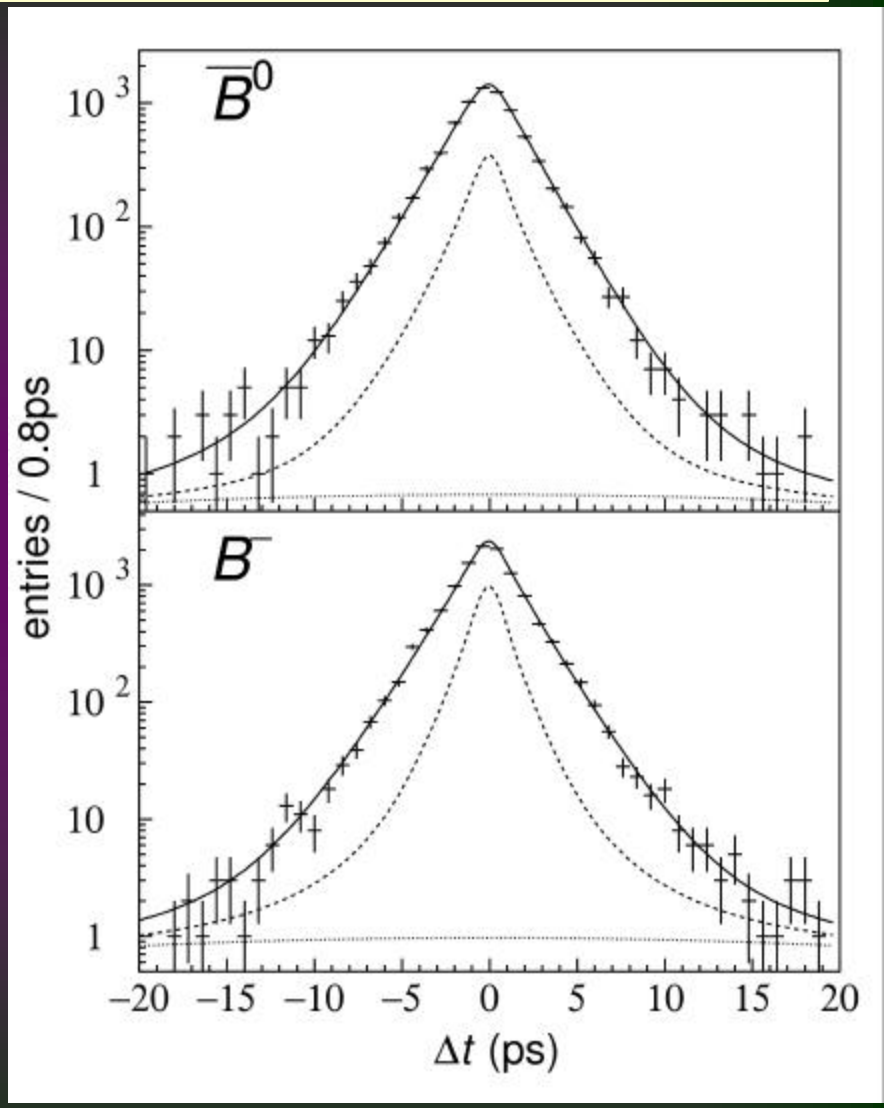
Simultaneous fit to B^0,B^-

$\tau(B0) = 1.554 \pm 0.030 \pm 0.019$ (ps)

$\tau(B-) = 1.695 \pm 0.026 \pm 0.015$ (ps)

$\tau(B-) / \tau(B0) = 1.091 \pm 0.023 \pm 0.014$

PRL 88, 171801 (2002)



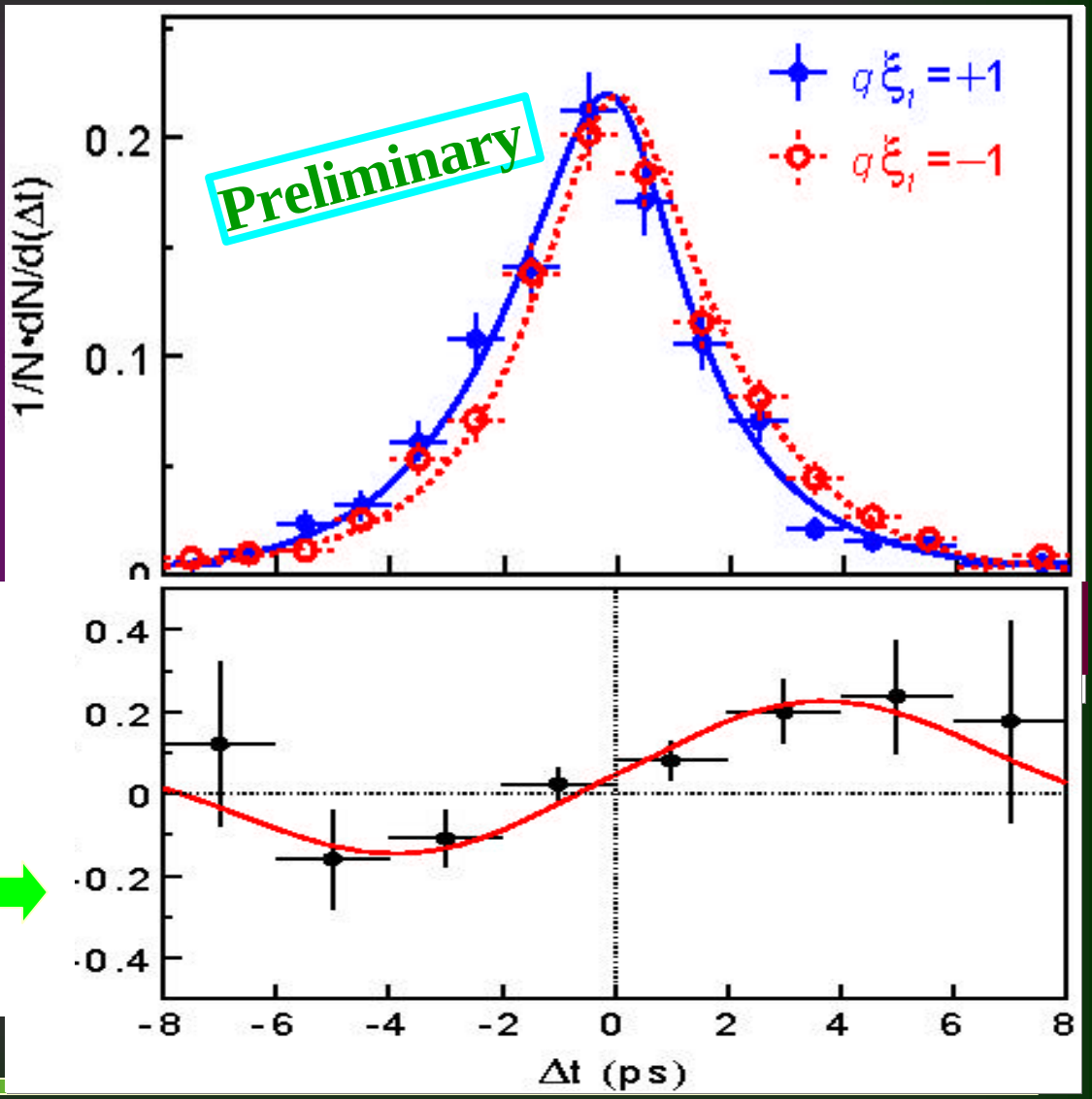
sin2ϕ1: Unbinned Maximum-likelihood Fit

1550 events 1137 LP01

sin2 f_1 =
0.82 ± 0.12 (stat)
± 0.05 (sys)

Raw data Asymmetry !

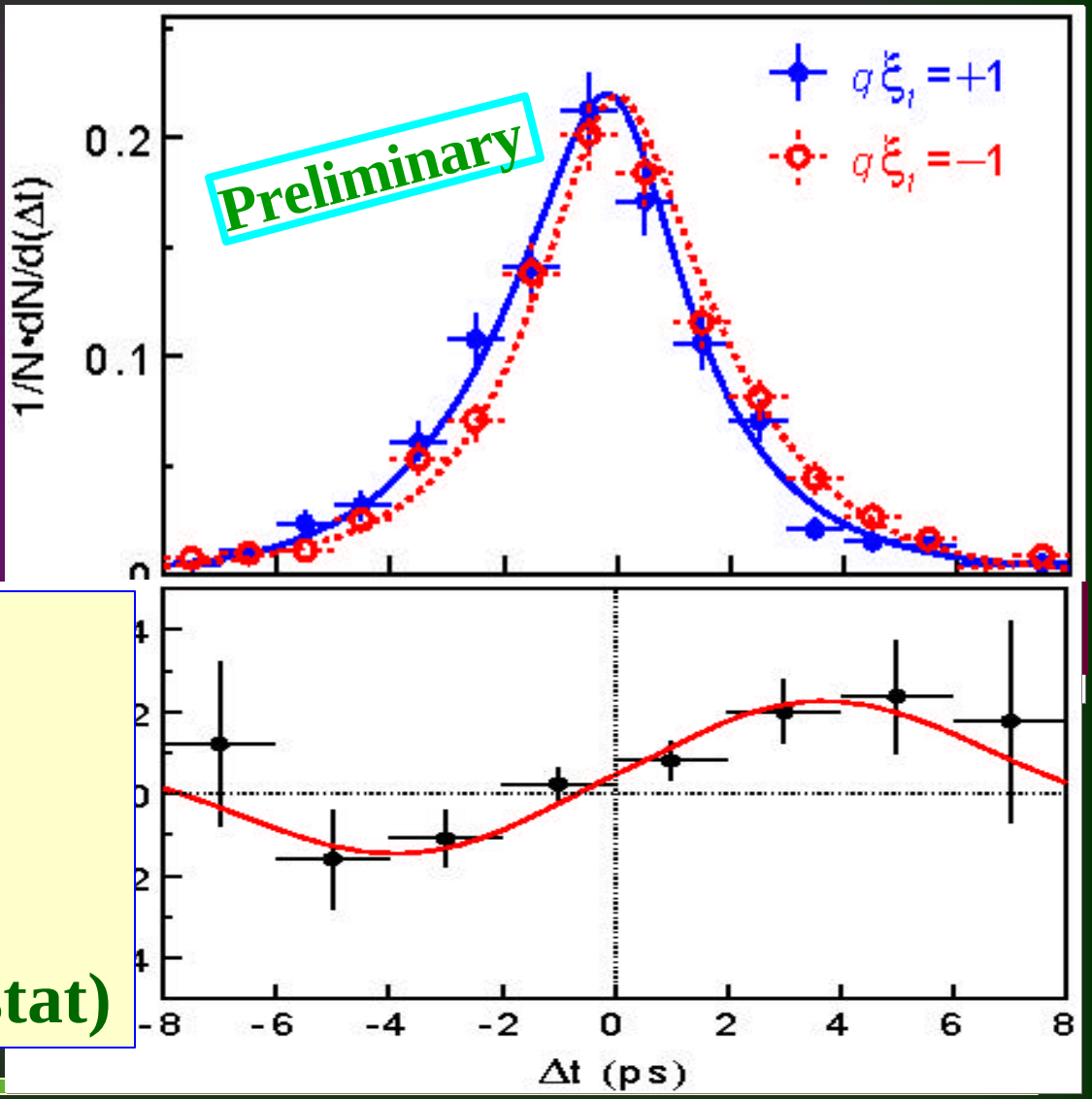
$$\frac{N(qx_f=-1) - N(qx_f=+1)}{N(qx_f=-1) + N(qx_f=+1)}$$



sin2ϕ1: Unbinned Maximum-likelihood Fit

1550 events 1137 LP01

sin2 f_1 =
0.82 ± 0.12 (stat)
± 0.05 (sys)

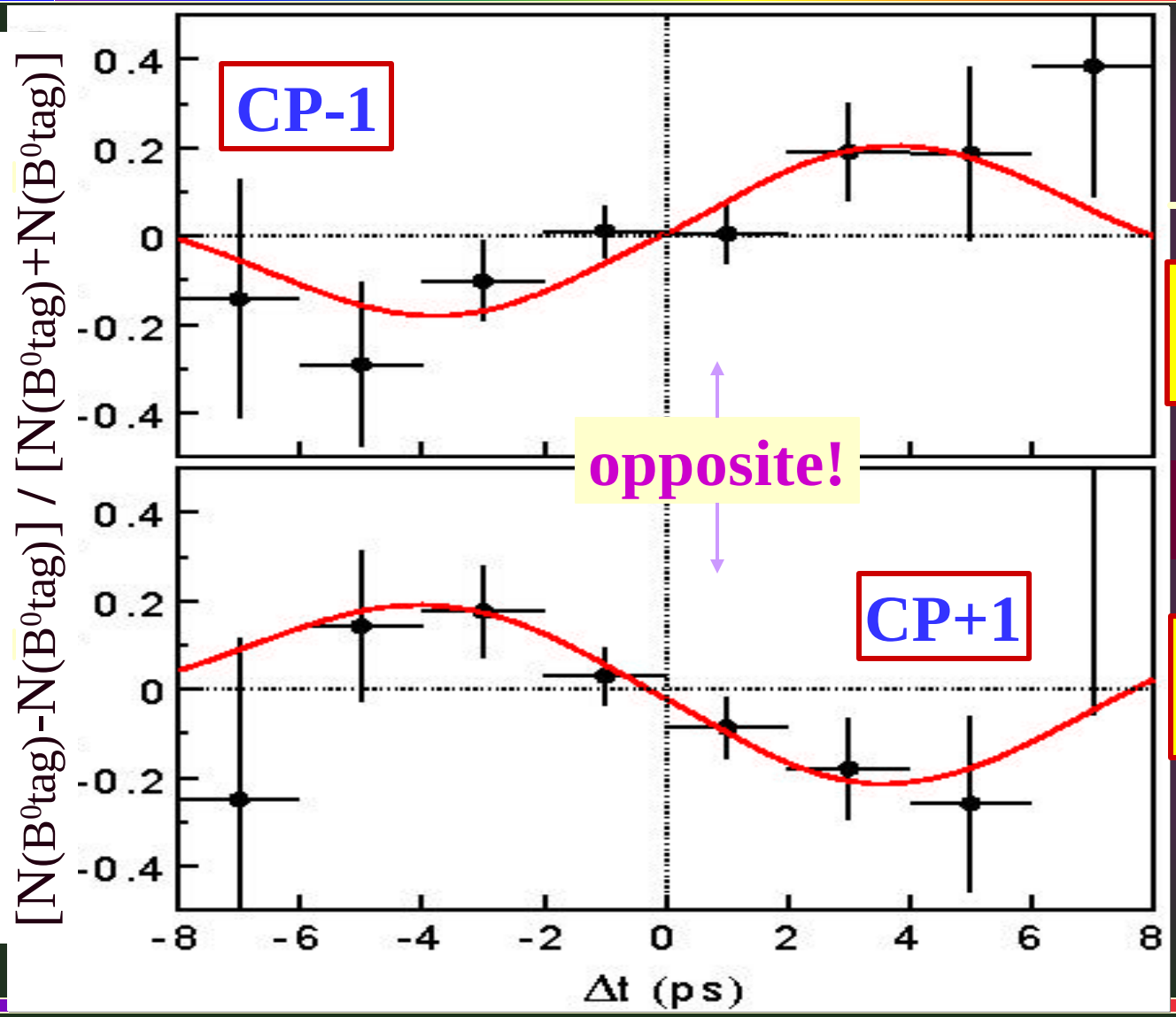


Test of direct CPV

$|l| = 1.01\ ^{+0.08}_{-0.07}$(stat)

"sin2f1" = 0.82 ± 0.12 (stat)

Raw Asymmetries



$\sin 2\phi_1$

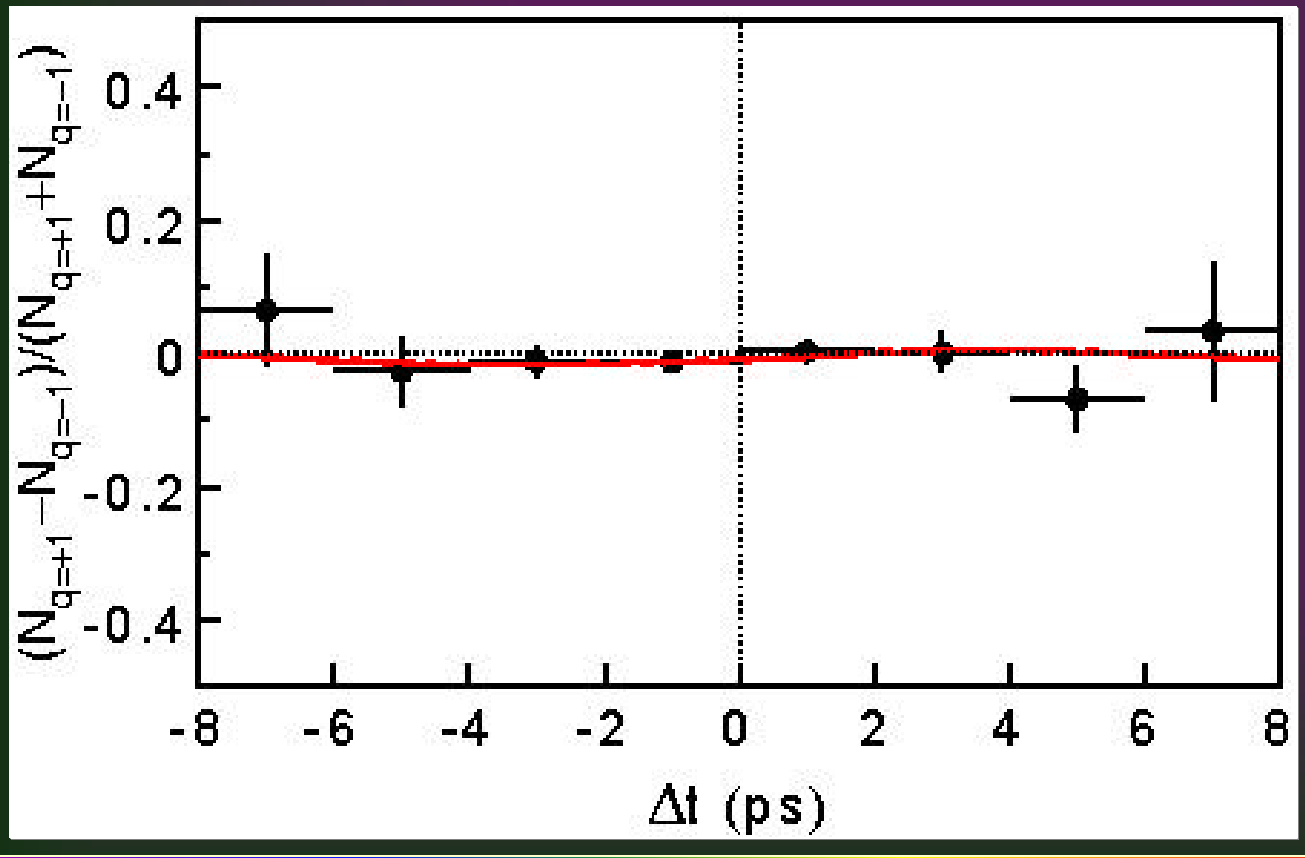
$0.69 \pm {}^{0.15}_{0.16}$

$1.14 \pm {}^{0.22}_{0.24}$

(statistical errors only)

Test of Null Asymmetry

use: $B^0 \to D^{(*)-} p^+$, $D^{*-} r^+$, $J/\psi K^*(K^+ p^-)$

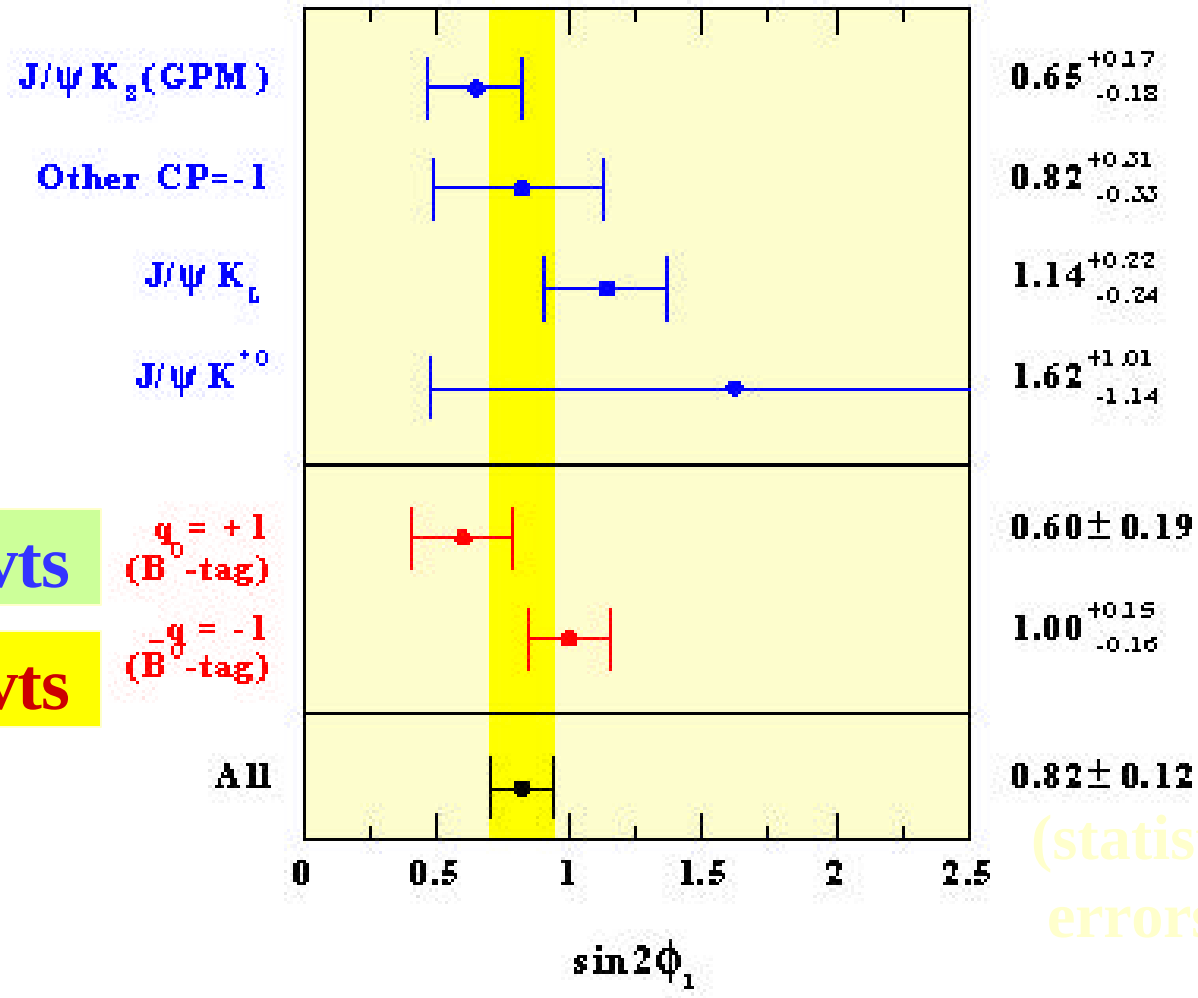


"sin2 ϕ_1"

0.05±0.04

(statistical error only)

sin2ϕ_1 from various subsamples



q=+1 785 evts

q=-1 765 evts

(statistical errors only)

sin2f1 : Systematic Errors

		LP01
Vertexing	$\pm$ 0.03	0.04
Flavor tagging	$\pm^{0.024}_{0.026}$	$+0.022$ -0.025
Resolution function	$\pm^{0.022}_{0.019}$	$+0.022$ -0.032
Background fraction(K_L)	$\pm^{0.014}_{0.015}$	0.02
Background (non K_L)	$\pm^{0.007}_{0.006}$	0.01
Δm_d and τ_{B0} errors	$\pm^{0.007}_{0.006}$	0.01
Total	$\pm$ 0.048	0.06

Preliminary

Why better precision required ?

- sin2f_1 in ***J/y Ks*** (and related)
  - Insensitive to New Physics: Boring ? No !
    - Important as the Standard Model "Anchoring Point"
    - Combination with other rare-decay CPV: a promissing road to the Physics beyond the Standard Model

- Examples of rare decays
  - B^0 ® *h'Ks* : New CPV phase search in penguin decays
    - → sin2ϕ1(***J/y Ks***) = "sin2ϕ1(*h'Ks*)" ??
    - → Talk by K-F. Chen in the "hot topics" session with 73 signal events
  - One of the most important inputs to the CKM fit

Conclusion

- KEKB: Great Achievement !
  - Lpeak = 7.25 x 10^{33} $cm^{-2}s^{-1}$
- Belle: Very Stable Operation
- $\sin 2\phi_1 = \mathbf{0.82 \pm 0.12\ (stat) \pm 0.05\ (sys)}$ **($41.8fb^{-1}$)**
  - Summer update with ~$90fb^{-1}$!
  - Test the SM with other CPV in rare B decays !

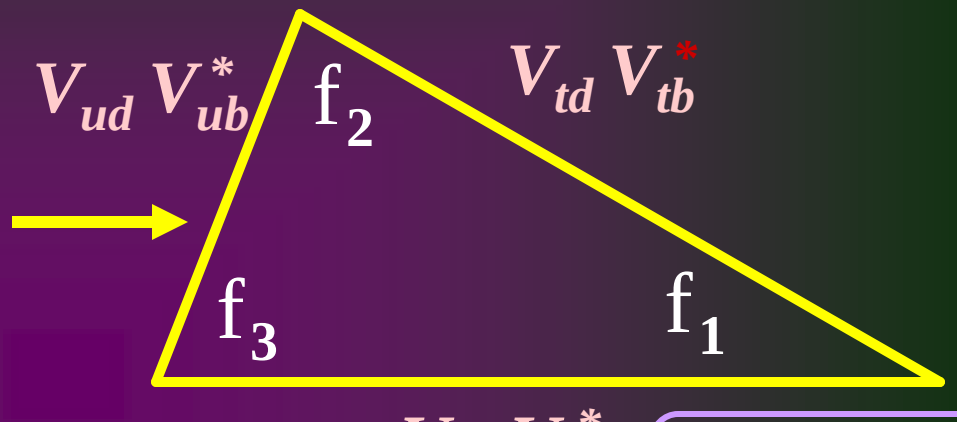
Exciting time will yet to come !

Backup Slides

Kobayashi-Maskawa model of CPV

CPV due to the complex phase in CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} V_{us} V_{ub} \\ V_{cd} V_{cs} V_{cb} \\ V_{td} V_{ts} V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



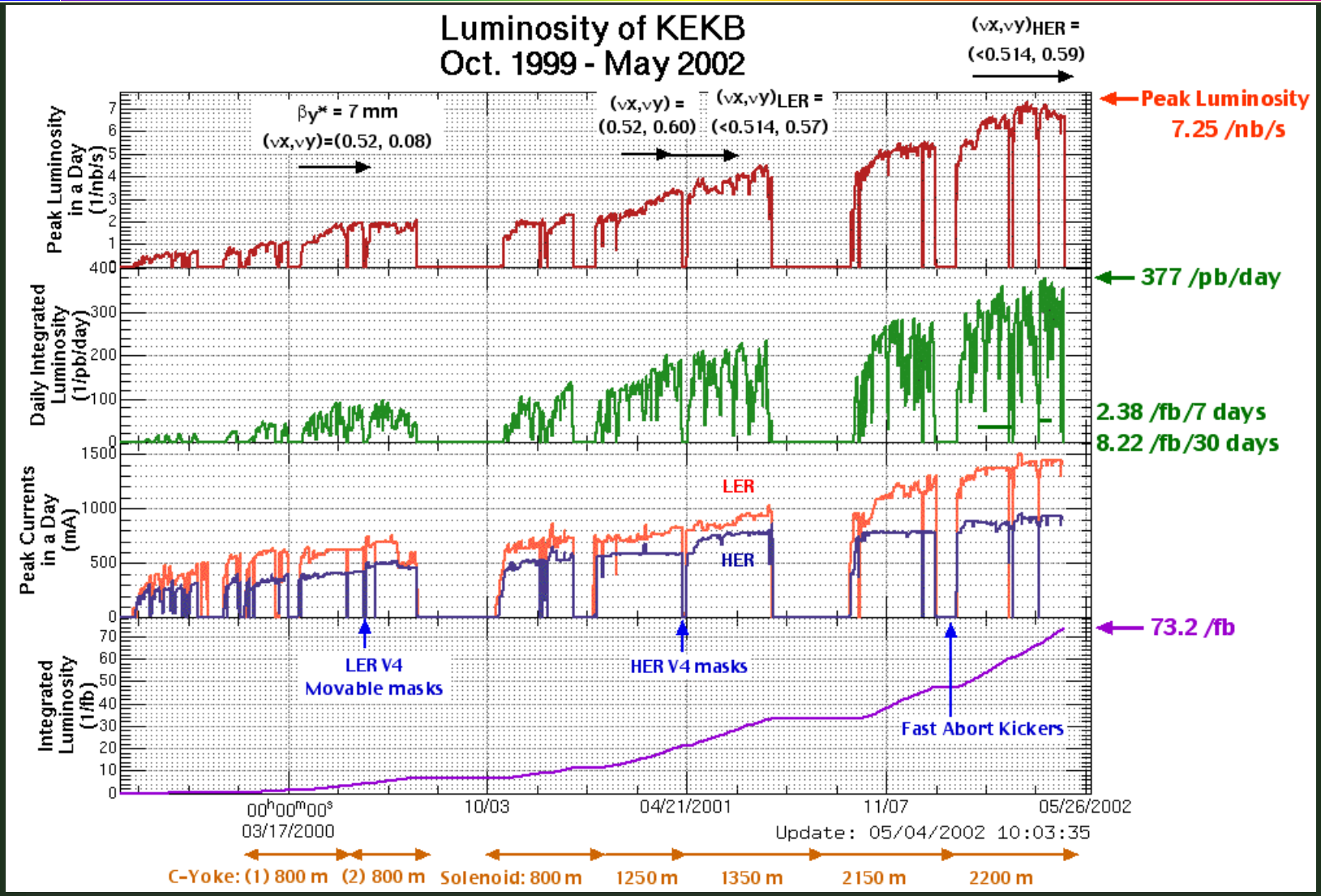
Unitarity triangle

Physics at Belle

- Discover CPV in B meson system (done !)
- Measure CKM elements (angles and lengths) with unprecedented precision to overconstrain
- Beyond the SM (e.g. a new CPV phase)

CKM

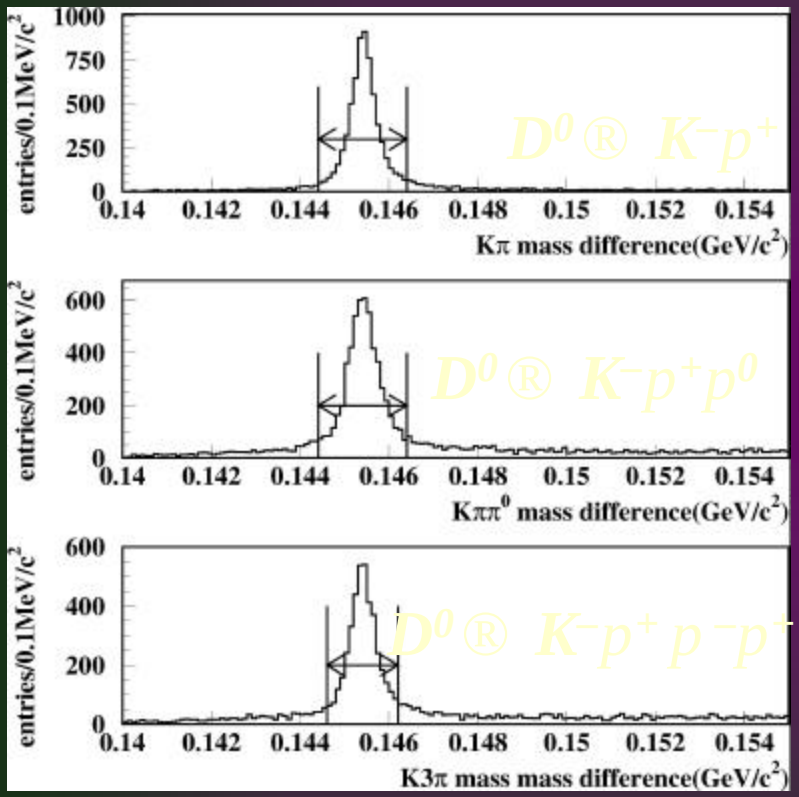
KEKB Luminosity



Control Samples

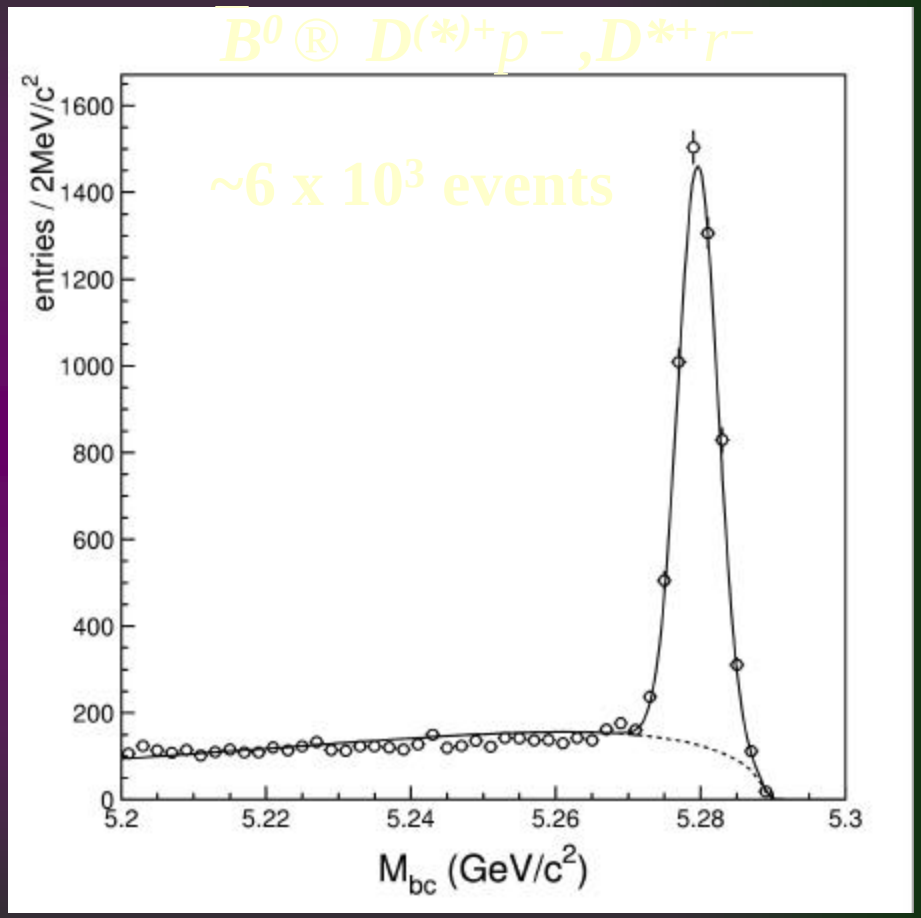
Semileptonic decays

$\bar{B}^0 \to D^{*+}(\to D^0\pi^+)l^-\nu$



Hadronic decays

$\bar{B}^0 \to D^{(*)+}\pi^-, D^{*+}\rho^-$



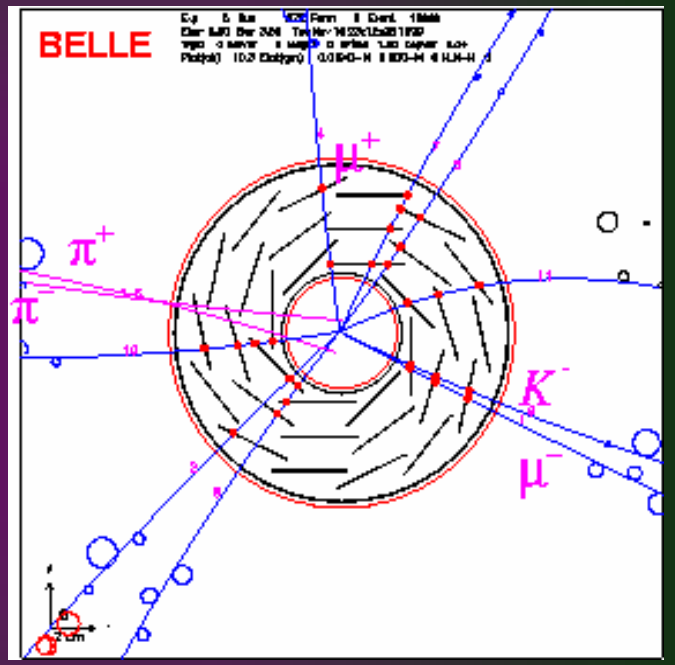
Used to evaluate performance of flavor tagging

Vertex Reconstruction

- For *CP*-side, use J/y $\rightarrow l^+l^-$
  - Reject poorly fit events.

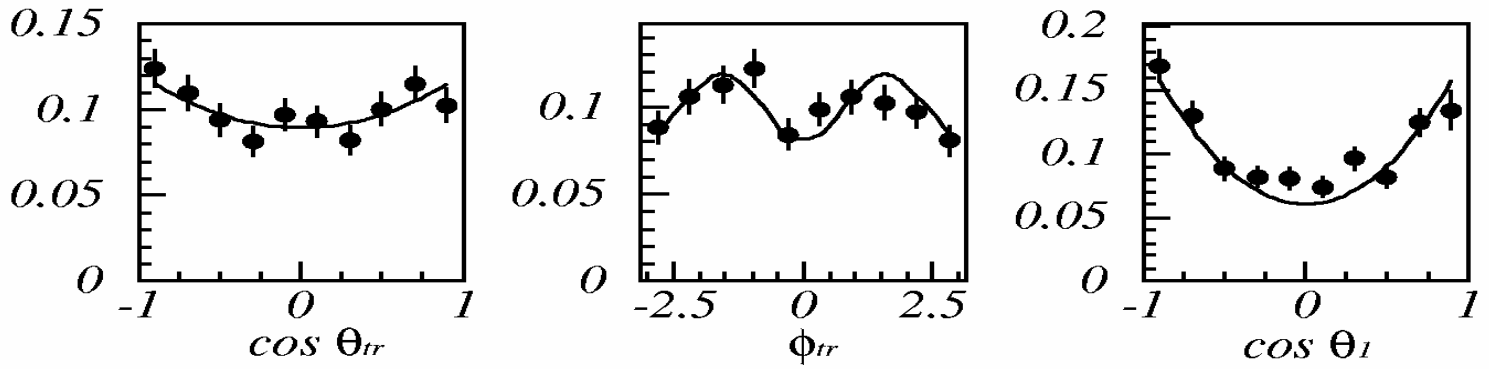
    dz_{CP} » 75 mm (rms)
- For *Tag*-side
  - use well fit tracks
  - iterate: discard worst track
  - dz_{tag} » 140 mm (rms)
- Require $|z_{CP} - z_{tag}|$<2mm (»10t_B)

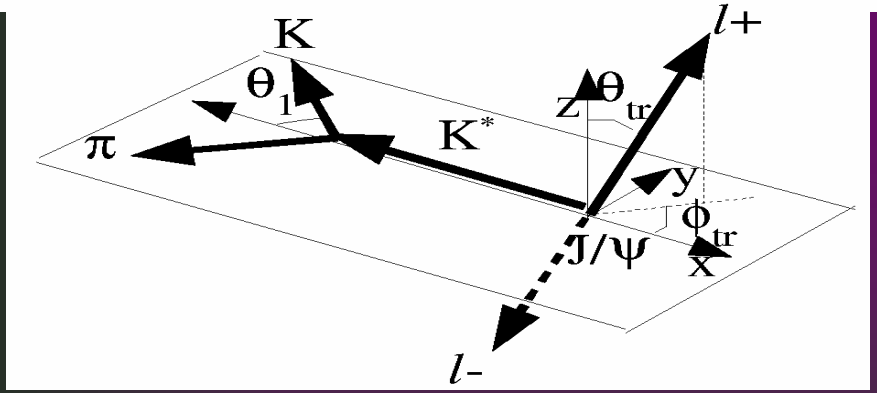
  s_{Dt} » 1.5 ps
- Tails » 3%; Effic. » 85%



J/ψK* Transversity Analysis

B → VV usable !





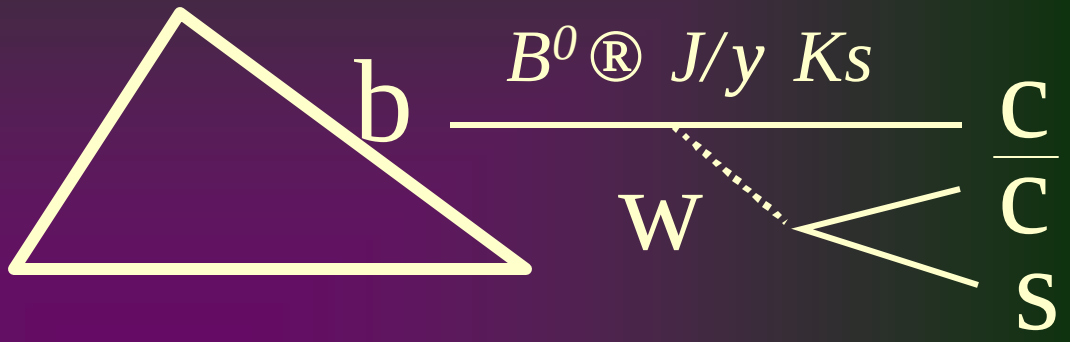
CP odd=19±4%

(See BELLE-CONF-0105)

$$P_{sig}(\ Dt, q_{tr}\ ) = (1-R_T)P_{CP=-1}\,(1+\cos^2 q_{tr})\ 3/8 + R_T\,P_{CP=+1}\,(\sin^2 q_{tr})\ 3/4$$

$B0 \to h'Ks$ Time-dependent CPV

Motivation



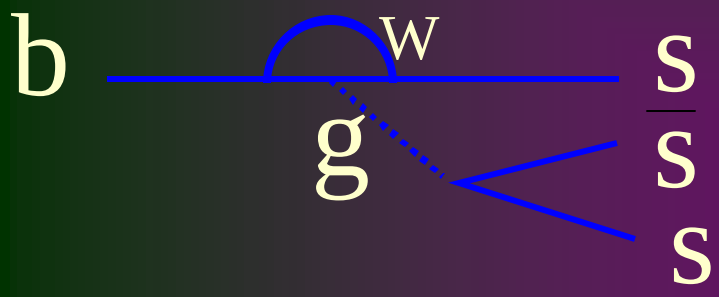
$$A_{CP}(Dt) = -x_f \sin 2f_1 \sin(Dm_d Dt)$$

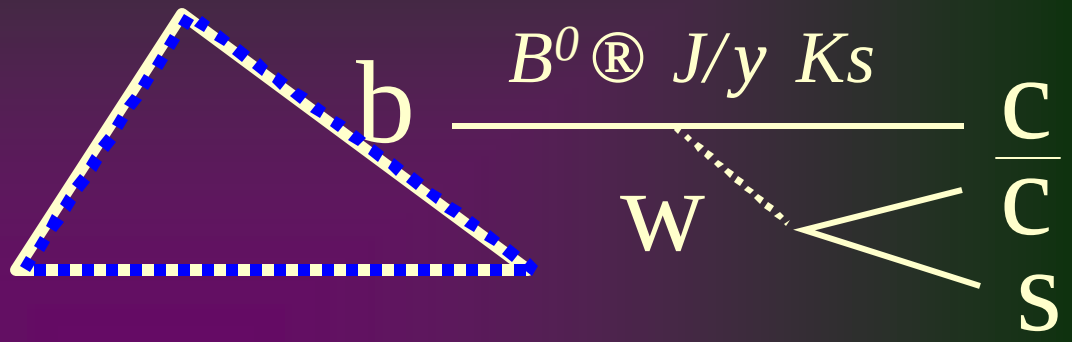
- Precise measurement of CPV in penguin decays : a powerful tool to search for a new CPV phase beyond the Standard Model (SM)
- Large branching fractions for inclusive and exclusive B → h' transition may be a hint.

$B0 \to h'Ks$ Time-dependent CPV

Motivation

$B^0 \to f\,Ks,\ h'Ks$



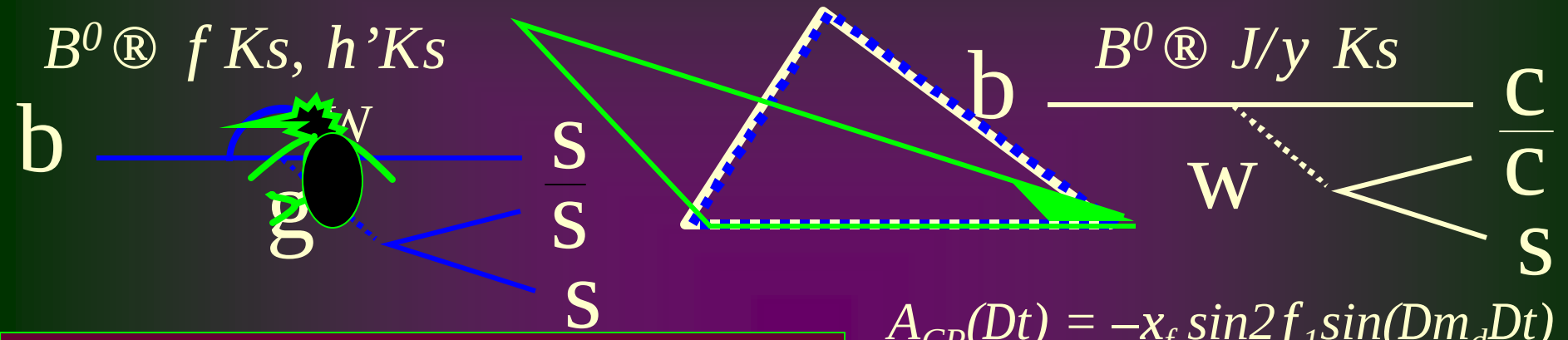


$$A_{CP}(Dt) = -x_f \sin 2f_1 \sin(Dm_d Dt)$$

- Precise measurement of CPV in penguin decays : a powerful tool to search for a new CPV phase beyond the Standard Model (SM)
- Large branching fractions for inclusive and exclusive B → h' transition may be a hint.

$B0 \to h'Ks$ Time-dependent CPV

Motivation



$A_{CP}(Dt) = -x_f \sin 2(f_1 + f_{NP}) \sin(Dm_d Dt)$

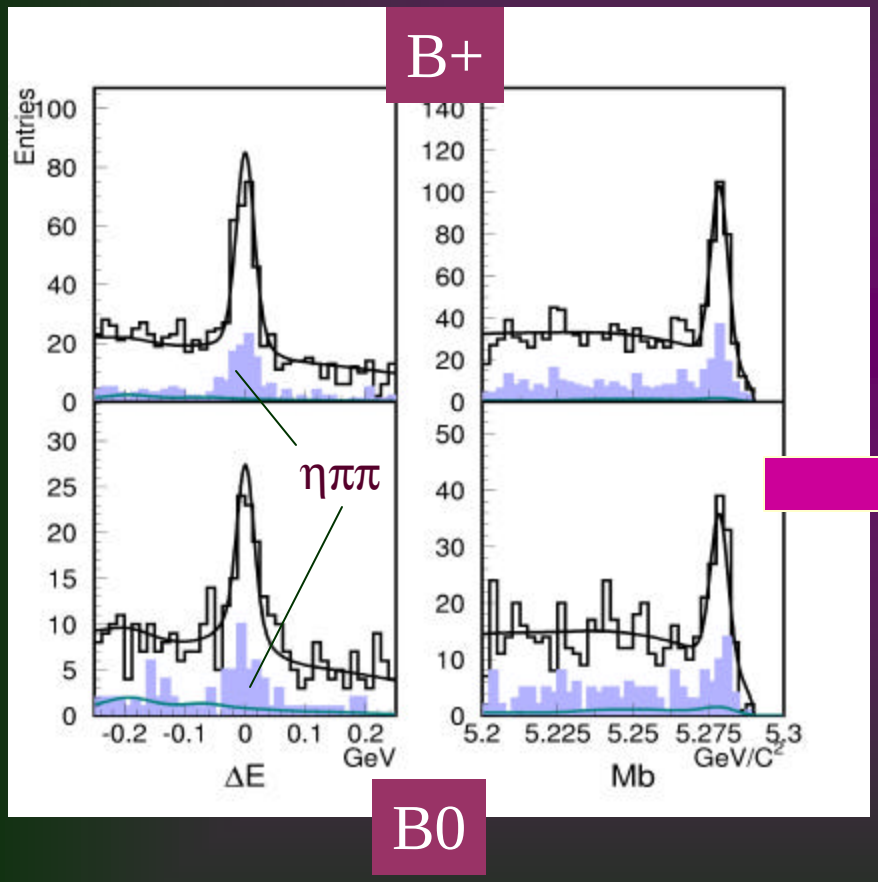
$A_{CP}(Dt) = -x_f \sin 2f_1 \sin(Dm_d Dt)$

New diagram and phase

- Precise measurement of CPV in penguin decays : a powerful tool to search for a new CPV phase beyond the Standard Model (SM)
- Large branching fractions for inclusive and exclusive B → *h'* transition may be a hint.

Reconstruction

Belle 41.8fb-1



B0 → η'Ks —— π+π- (68.60 ± 0.27)%

- ργ (29.5 ± 1.0)%
  - π+π- (~100)%
- ηπ+π- (44.3 ±1.5)%
  - γγ (39.33 ±0.25)%

B0 Yields

N(ργ Ks) = 45.5 $^{+8.6}_{-7.9}$

N(ηππ Ks) = 27.7 $^{+6.2}_{-5.5}$

More will be given in the "hot topic" session (K-F. Chen)