Recent results from Belle

Peter Križan
Univ. of Ljubljana and J. Stefan Institute

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- Introduction
- Experimental apparatus
- Warming up: measurement of $\sin 2\phi_1 = \sin 2\beta$
- Measurement of CP violation in:
  - $B^0 \to \pi^+\pi^-$
  - $B^0 \to \eta' K_S$, ϕK_S and $K^+K^-K_S$
  - $B^0 \to J/\psi\pi^0$
- Measurement of $b \to s\ell^+\ell^-$ decays
- What comes next?
- Summary

CP Violation

Fundamental quantity: distinguishes matter from anti-matter.

A bit of history:

- First seen in K^0 decays in 1964
- Discovery of $B^0 - \bar{B}^0$ mixing at ARGUS in 1987 indicated that the effect could be large in B decays
- Many experiments were proposed to measure it, some of them were actually built, and some general purpose experiments tried to do it
- Measured in the $B^0 - \bar{B}^0$ system in 2001 by the two dedicated spectrometers Belle and BaBar at asymmetric e^+e^- colliders - B factories

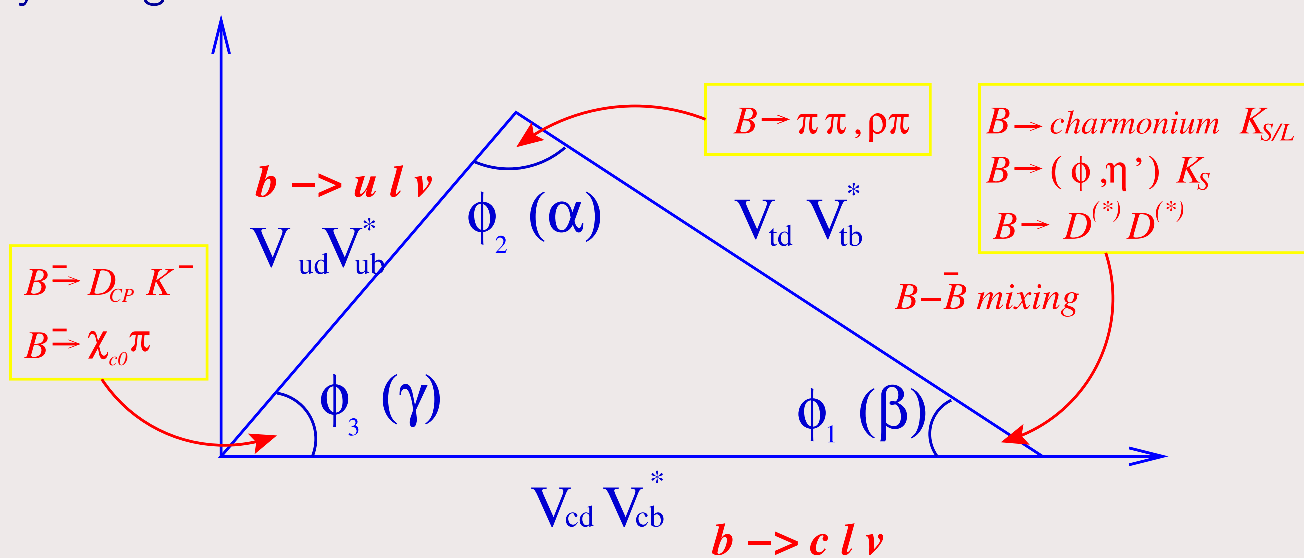
CP Violation in the Standard Model

CP violation is accommodated as an irreducible phase in the weak interaction mixing matrix (CKM)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\varrho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\varrho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

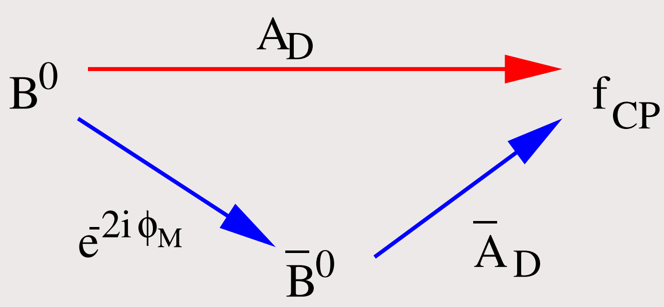
Unitarity of V leads to conditions the matrix elements have to satisfy, e.g. $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0.$

$\longrightarrow$ unitarity triangle



CP Violation in B decays

CP violation effects in B decays are potentially large due to the interference of amplitudes for the direct decay to a CP final state f_{CP} and the decay after mixing.



This results in a decay rate asymmetry:

$$A_{CP}(t) \equiv \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})}$$

$$= \mathcal{A}_f \cos \Delta m_d t + \mathcal{S}_f \sin \Delta m_d t$$

$$\mathcal{A}_f = \frac{|\lambda_f^2| - 1}{|\lambda_f^2| + 1}$$

$$\mathcal{S}_f = \frac{2Im(\lambda_f)}{|\lambda_f^2| + 1}$$

$$\lambda_f \equiv e^{-2i\phi_M} \frac{\mathrm{A_D}(\bar{B} \to f_{CP})}{\mathrm{A_D}(B \to f_{CP})}$$

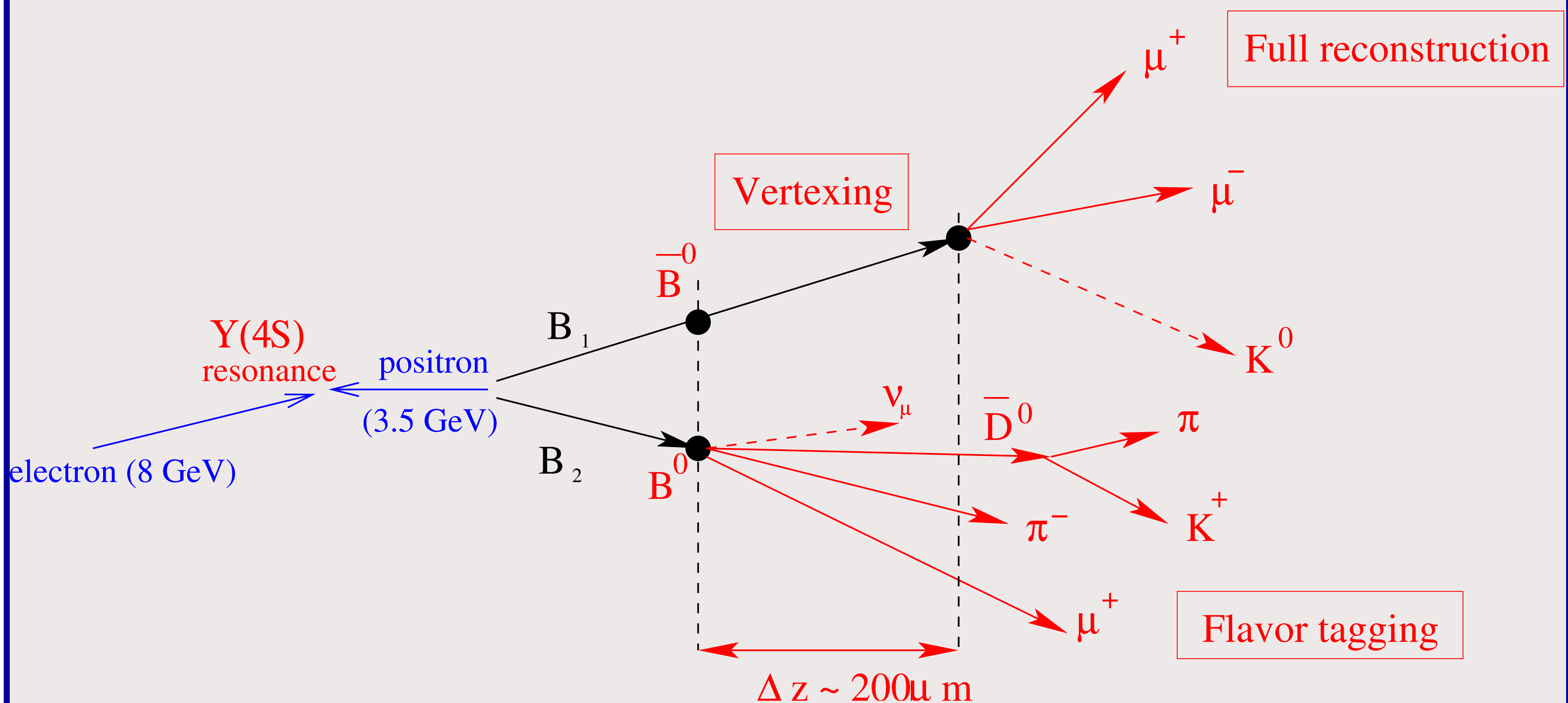
Standard model predictions

	$b \to c\bar{c}s$	$b \to c\bar{c}d$	$b \to s\bar{s}s$	$b \to u\bar{u}d$
example	$J/\psi K_S$	$J/\psi \pi^0$	ϕK_S	$\pi^+\pi^-$
$\mathcal{A}_f$	0	0	small	$\neq 0$
$\mathcal{S}_f$	$\sin 2\phi_1$	$\sin 2\phi_1$	$\sin 2\phi_1$	"$\sin 2\phi_2$"

N.B. $\mathcal{A}_f \neq 0 \to \Gamma(\bar{B} \to f_{CP}) \neq \Gamma(B \to f_{CP})$

$\to$ direct CP violation

Measurement of CP violation - principle



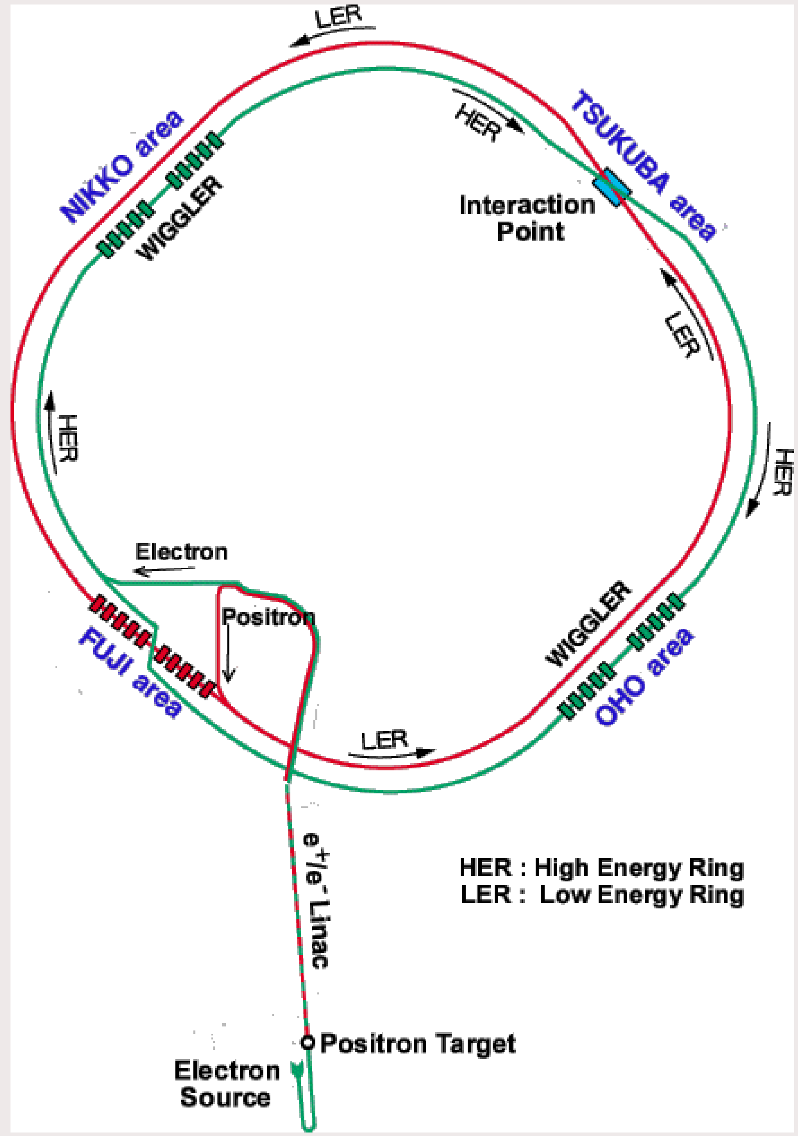
Needed:
a large number of $B\bar{B}$ pairs (100 M)
$\rightarrow B$-factory $=$
a high luminosity e^+e^- collider
with asymmetric beam energies

and a spectrometer with
- precise vertexing (Δt from Δz)
- accurate tracking in magnetic field (momenta of decay products)
- efficient identification of e, μ, π, K (tagging of the B flavour)

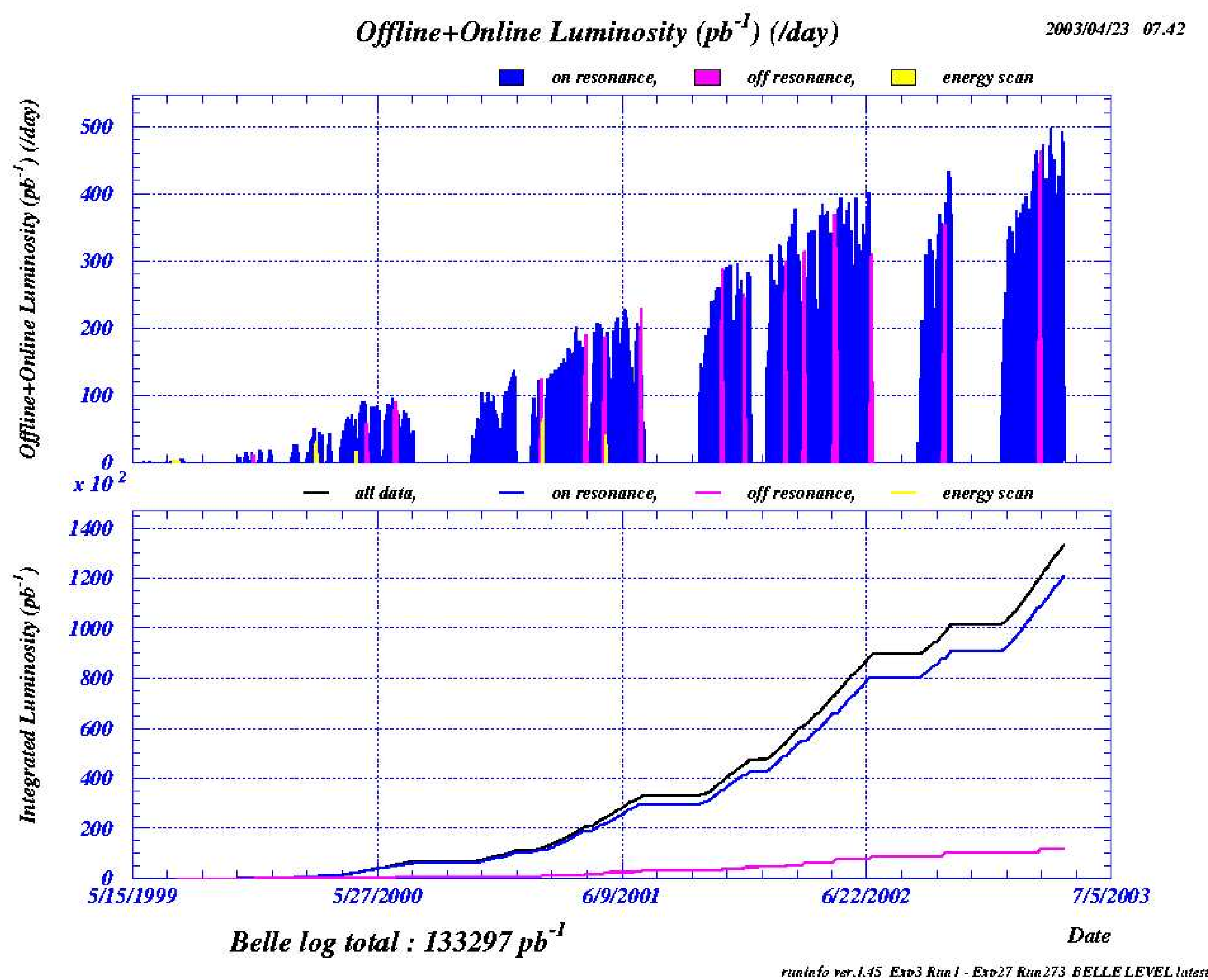
KEKB Accelerator performance 1

peak luminosity $= 9.683 \cdot 10^{33}$ cm^{-2}s^{-1}

integrated luminosity records:
day = 513.6 /pb
week = 2.981 /pb
month = 11.433 /pb
total = 132.971 /fb (Apr. 22, 2003)



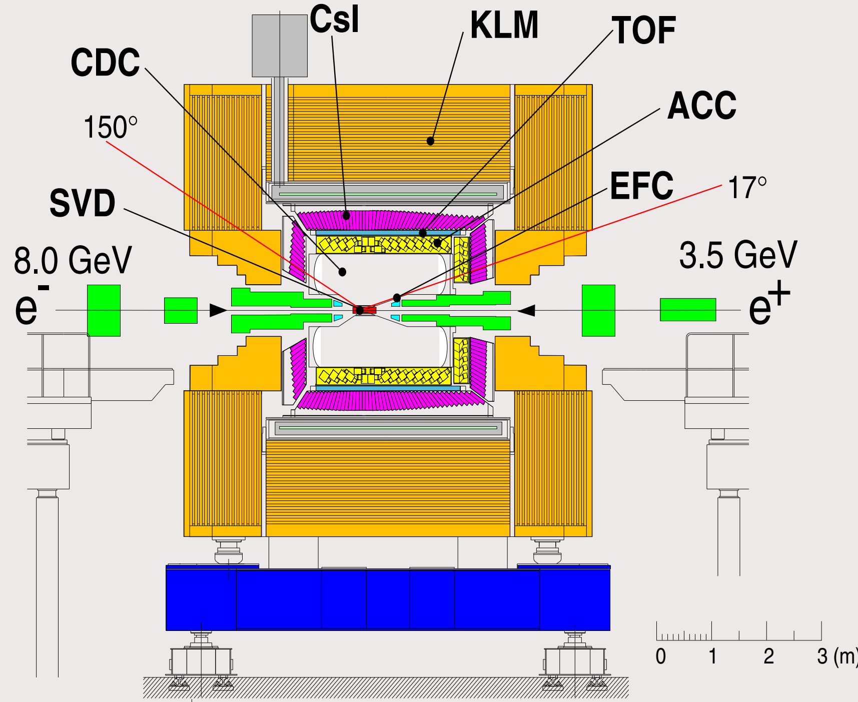
KEKB accelerator performance 2



Belle Detector performance

Tracking and vertexing

- ✦ Central Drift Chamber (CDC)
  50 layers
  $\frac{\sigma_{p_T}}{p_T} \approx 0.35\%$ at 1 GeV/c
- ✦ Silicon Vertex Detector (SVD)
  3 double-sided silicon layers
  impact parameter $\sigma = 55\ \mu$m
  for 1 GeV/c tracks (90^0)



Particle identification:

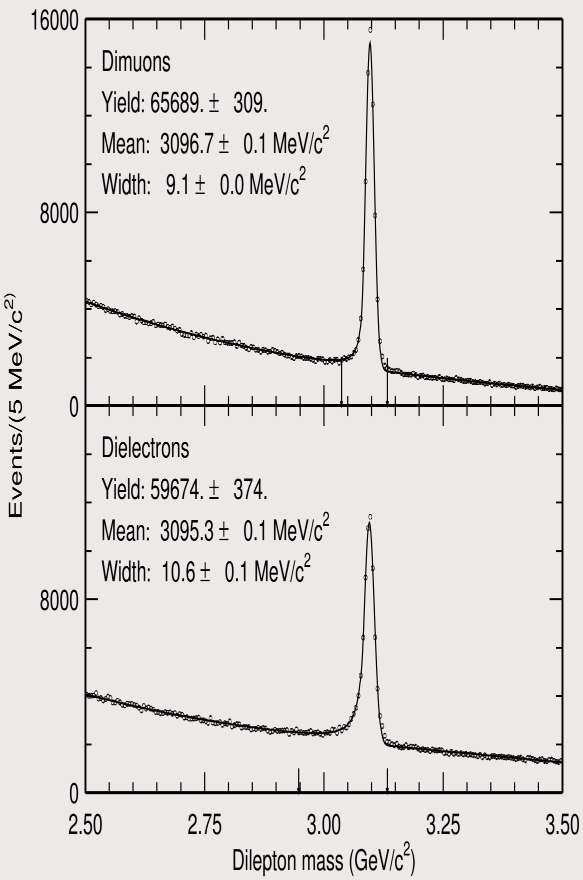
Identify $K^{\pm}$ up to 3.5 GeV/c (efficiency $\approx 90\%$, fake rate $\approx 6\%$)

- ✦ Aerogel Cherenkov Counter (ACC): ref.index 1.01-1.03
- ✦ Time of Flight (TOF): $\sigma = 95$ ps
- ✦ dE/dx in CDC: $\sigma_{dE/dx} \approx 7\%$

Electron id: Electromagnetic calorimeter (CsI) $\frac{\sigma_E}{E} \approx 1.8\%$ at 1 GeV

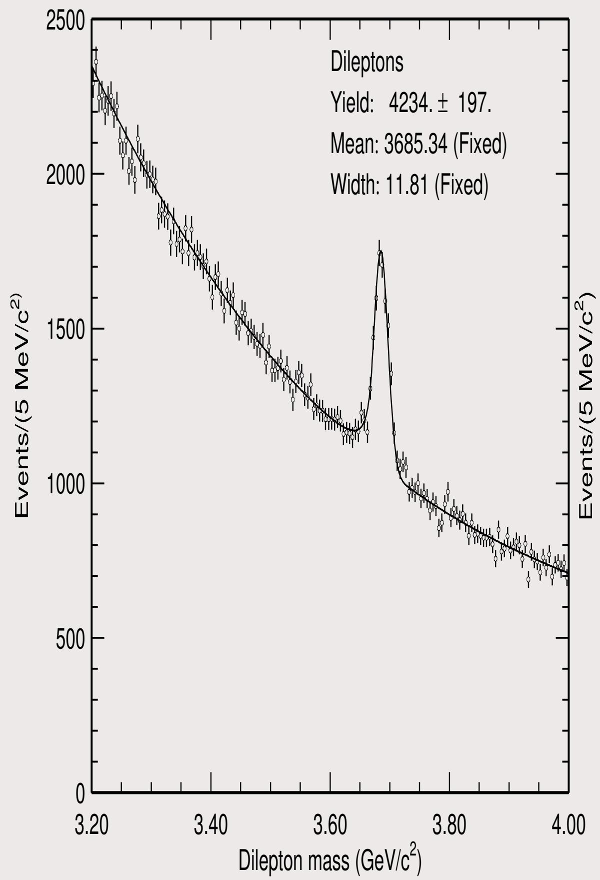
K_L and Muon detector (KLM): 14 layers, $\epsilon_\mu > 90\%$ at fake rate 2%

Reconstruction of $B^0 \to (c\bar{c})K_S$ decay modes



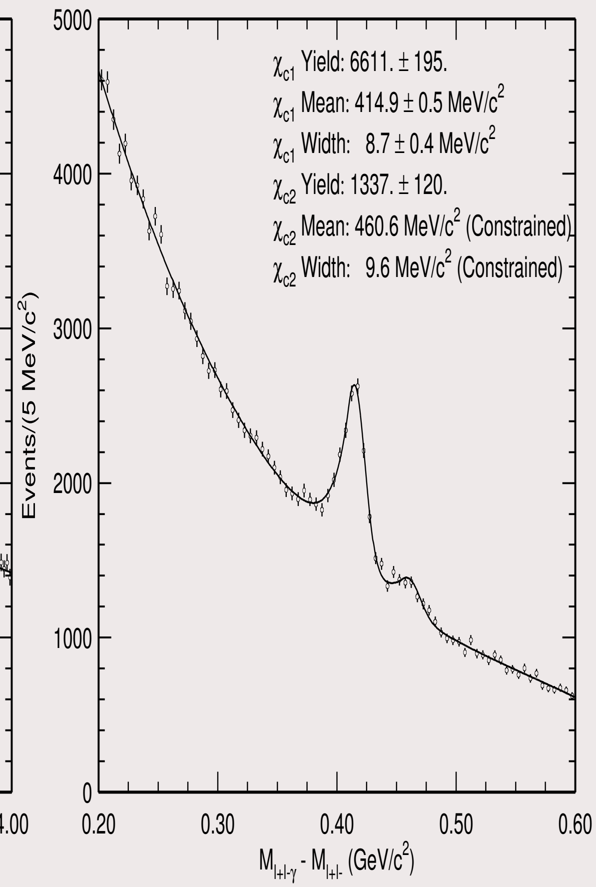
$J/\psi \to \mu^+\mu^-, e^+e^-$

$\sigma_M = 9.6(10.7)\mathrm{GeV/c^2}$



$\psi(2s) \to \mu^+\mu^-, e^+e^-$

$\sigma_M = 12.1\mathrm{GeV/c^2}$



$\chi_{c1}, \chi_{c2} \to J/\psi\gamma$

$\sigma_{\Delta M} = 7.0\mathrm{GeV/c^2}$

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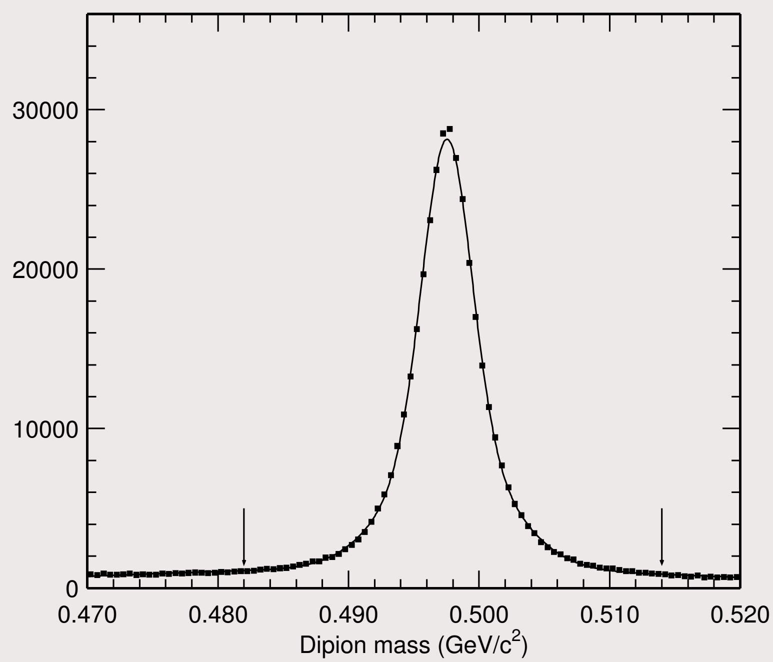
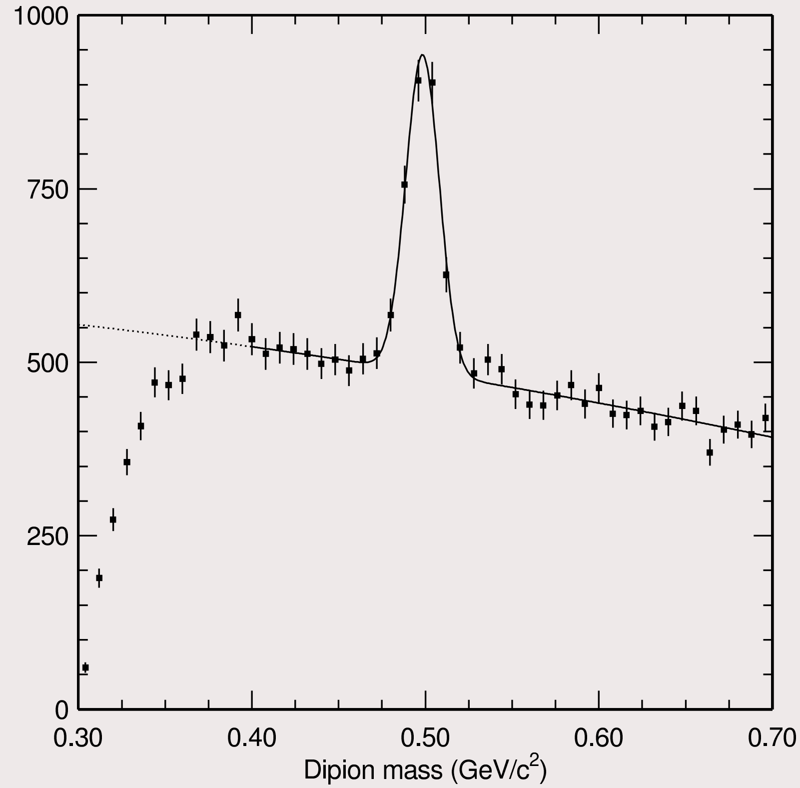
Reconstruction of $B^0 \to (c\bar{c})K_S$ decay modes

$K_S \to \pi^+\pi^-$

$\sigma_M = 4.1 \mathrm{GeV/c^2}$



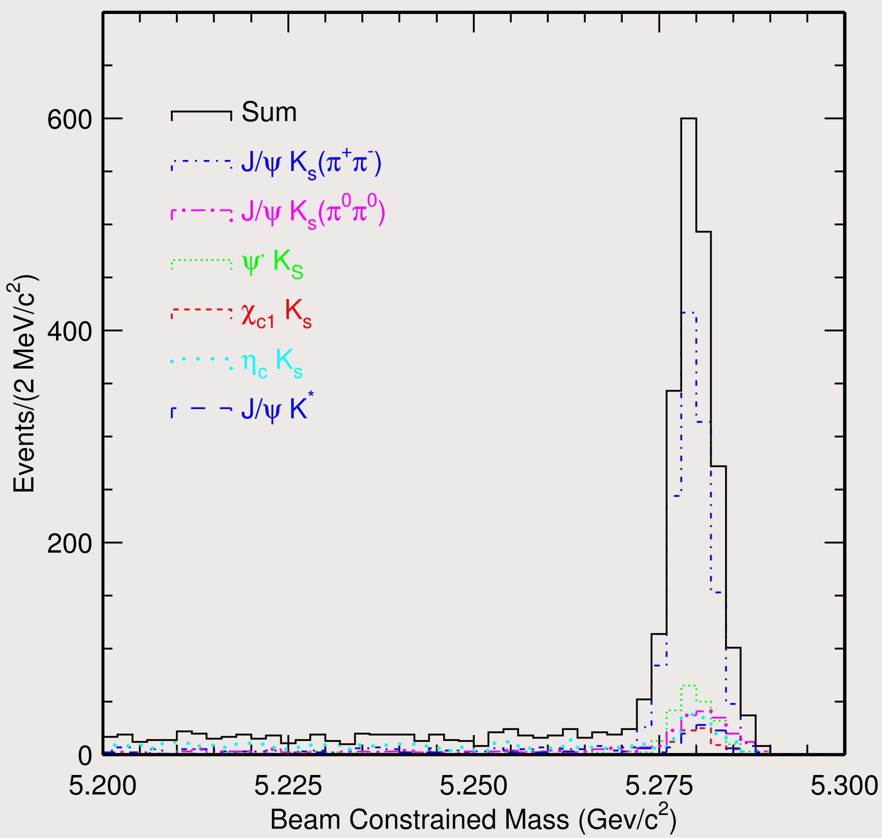


$K_S \to \pi^0\pi^0$

$\sigma_M = 9.3 \mathrm{GeV/c^2}$

Reconstruction of $b \to c\bar{c}s$ CP eigenstates

Reconstructed decay modes for full statistics (78 fb^{-1}, 85M $B\bar{B}$)



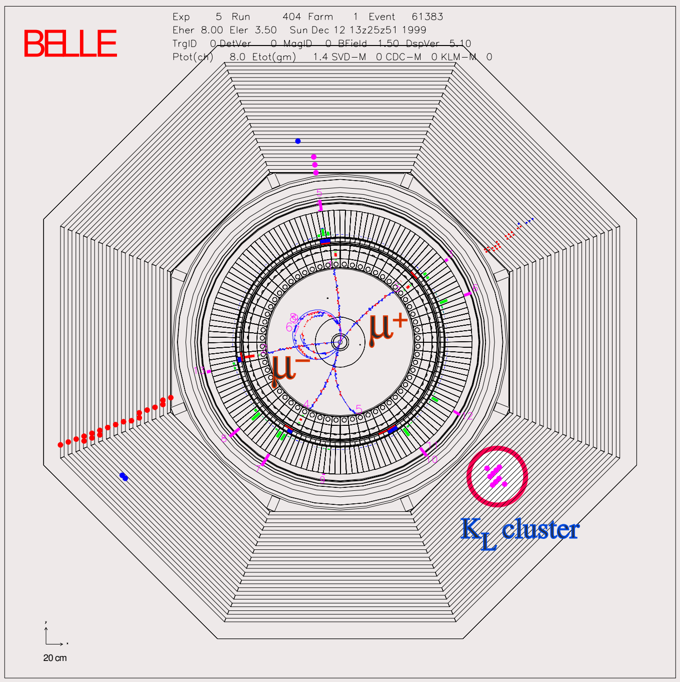
$$M_{bc} = \sqrt{E^2_{\text{beam}} - \vec{p}^2_{\text{Bcandidate}}}$$

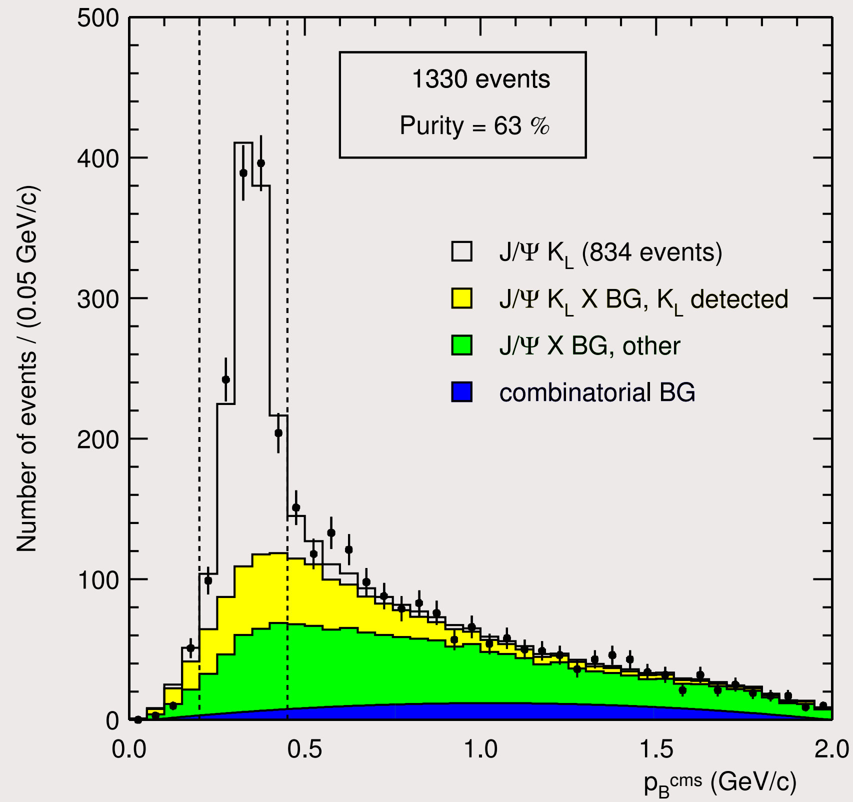
$B^0 \to$	events	$\frac{S}{S+N}$
$J/\psi K_S(K_S \to \pi^+\pi^-)$	1285	.976
$J/\psi K_S(K_S \to \pi^0\pi^0)$	188	.824
$\psi(2S)K_S$		
$(\psi(2S) \to \ell^+\ell^-)K_S$	91	.957
$(\psi(2S) \to J/\psi\pi^+\pi^-)$	112	.911
$\chi_{c1}K_S$	77	.958
$\eta_c(\eta_c \to K_S K\pi)K_S$	72	.646
$\eta_c(\eta_c \to KK\pi^0)K_S$	49	.725
$\eta_c(\eta_c \to p\bar{p})K_S$	21	.936
$J/\psi K^*(K^* \to K_S\pi^0)$	101	.917
total $CP = -1$	1996	.935
$J/\psi K_L$, $CP = +1$	1330	.627
Total	3326	.807

2958 events are used in the fit

Reconstruction of $CP = +1$: $B^0 \to J/\psi K_L$

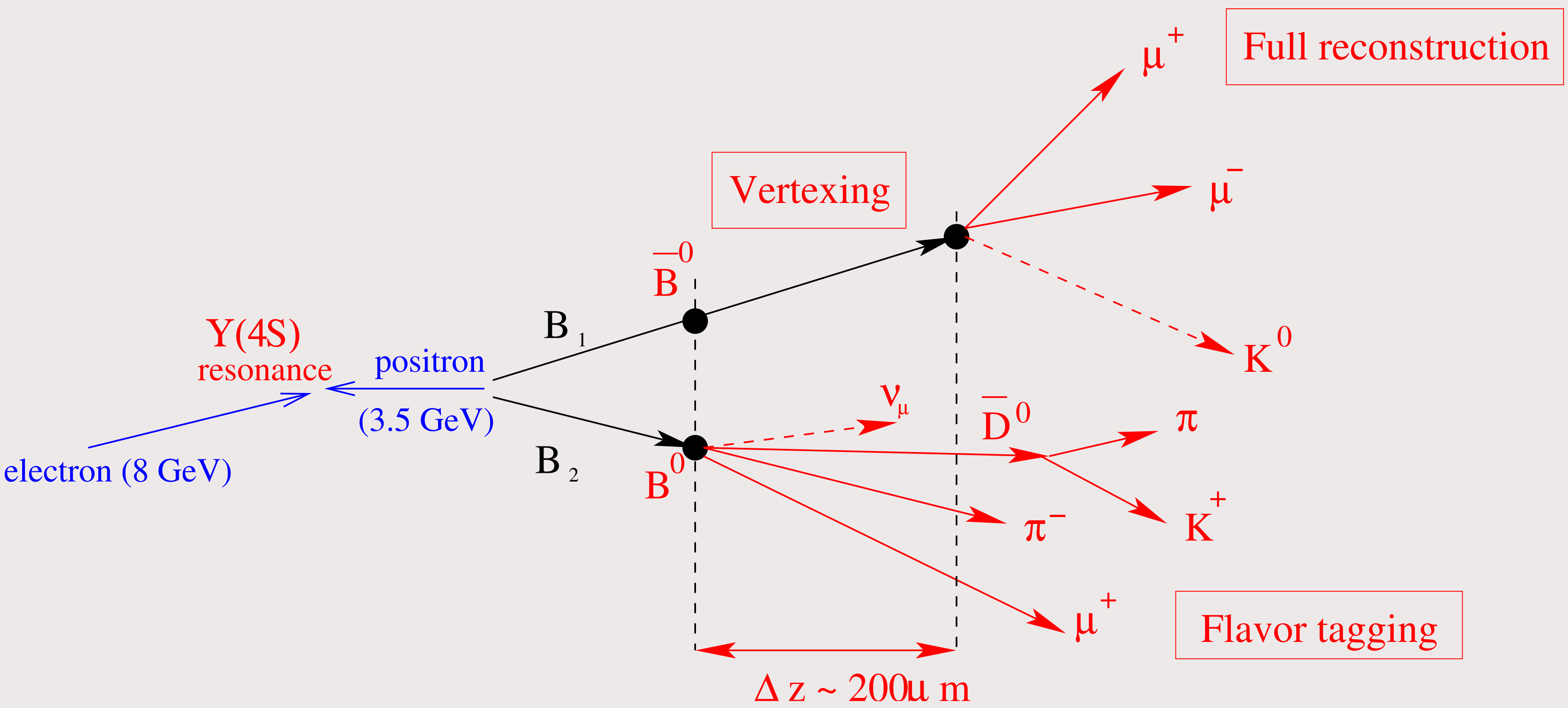
- detection of K_L in KLM and ECL
- K_L direction, no energy





- $p^* \approx 0.35$ GeV/c for signal events
- background shape is determined from MC, and its size from the fit to the data

Measurement of CP violation - continued



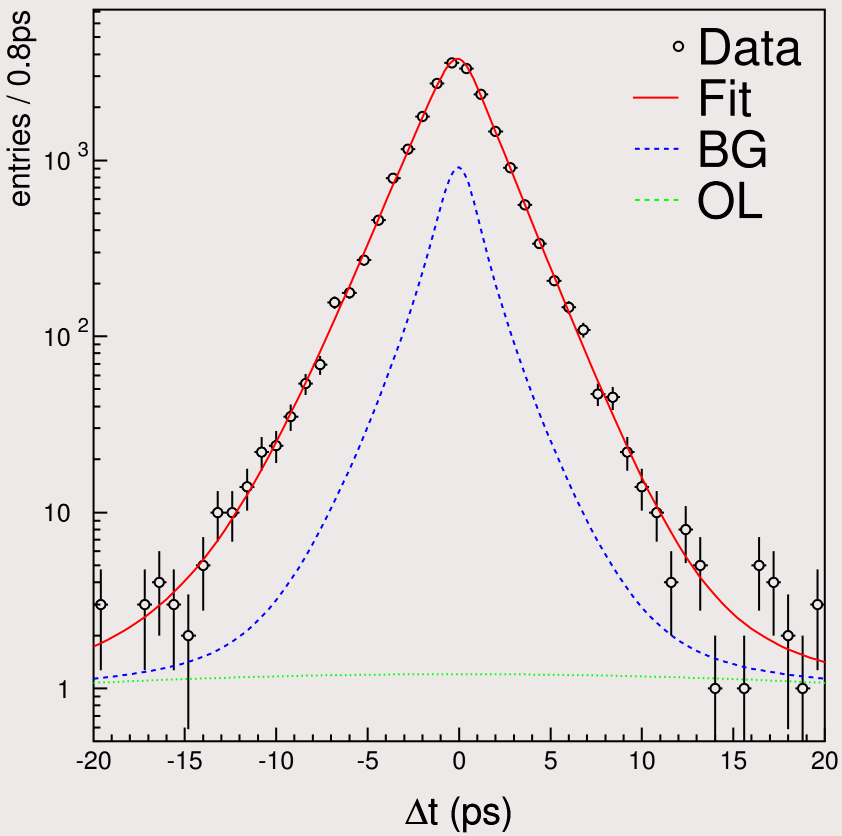
Determine Δt from $\Delta z = \beta\gamma c \Delta t$:

- ✦ clock start: resolution on tag side 140 μm ($\epsilon = 91\%$) - charm decays
- ✦ clock stop: resolution on CP side 75 μm ($\epsilon = 92\%$)

N.B. typically $\Delta z = \beta\gamma c \tau_B = 200\ \mu$m

Vertexing - check with lifetime measurement

Use $B^0 \to D^- \pi^+$, $D^{*-} \pi^+$, $D^{(*)-} \rho^+$, $B^0 \to J/\psi K_S$ and $B^0 \to J/\psi K^{*0}$ decays



- time resolution: 1.43 ps
- B^0 lifetime 1.551 ± 0.018 (stat) ps
- PDG: 1.542 ± 0.016 ps

Flavour tagging 1

Identify $B^0/\bar{B}^0$ by the charges of the decay products of the associated B.

Inclusive leptons

- high momentum ℓ^- — $b \to c\ell^-\nu$
- intermediate momentum ℓ^+ — $c \to s\ell^+\nu$

Inclusive hadrons

- high momentum π^+ — $B^0 \to D^{(*)-}\pi^+,\ D^{(*)-}\rho^+(\rho^+ \to \pi^+\pi^0)$, ...
- intermediate momentum K^+ — $\to K^+X$
- low momentum π^- — $D^{(*)-} \to \bar{D}^0\pi^-$

$\to$ tagging variable q

$q = +1$ if the tagging B is a B^0, $q = -1$ if the tagging B is a $\bar{B}^0$.

Efficiency $> 99.5\%$, $\epsilon_{\text{effective}} = 28.8 \pm 0.5\%$

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Flavour tagging 2

Tagging is not perfect: there is always a chance w that the tag is fake (less for leptons, more for kaons).

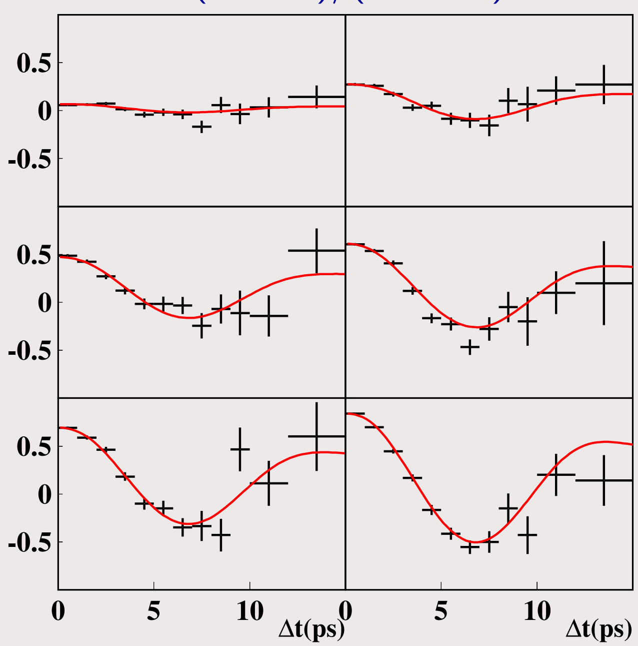
$\longrightarrow$ The asymmetry oscillation is reduced, $\sin \Delta m_d t \rightarrow (1-2w) \sin \Delta m_d t$.

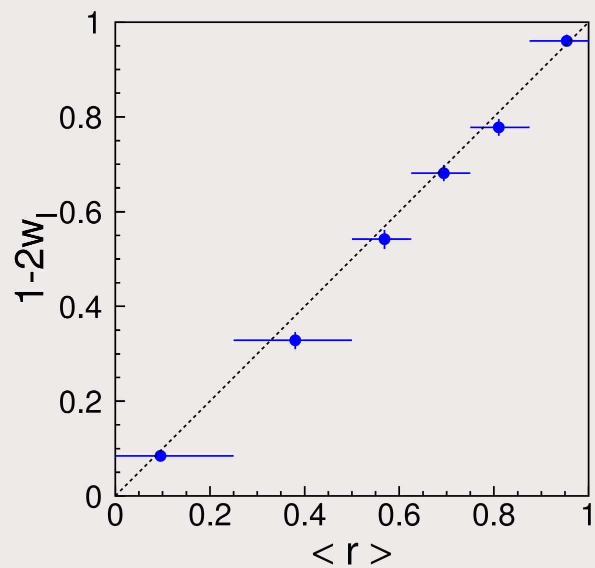
$\longrightarrow$ Needed: w for each event.

Classify events into six categories in a tag quality variable r.

Calibrate the relation $(1-2w)$ vs. r with data: measure the $B^0 \bar{B}^0$ mixing amplitude (using $\bar{B}^0 \rightarrow D^{*+} \ell^- \nu$, $D^{(*)+}\pi^-$ and $D^{(*)+}\rho^-$ decays) in 6 intervals in r

(OF-SF)/(OF+SF)





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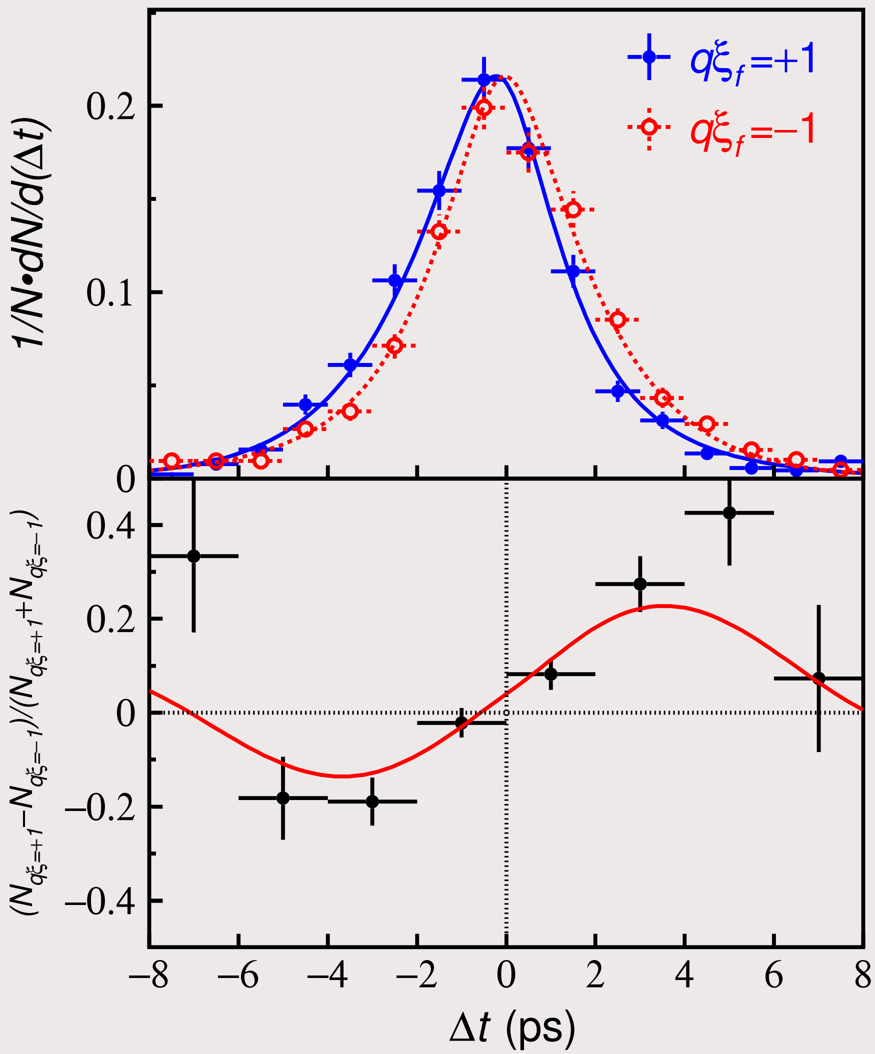
Result with full statistics (78 fb^{-1}, 85M $B\bar{B}$)



CP is violated! Red points differ from blue.

Red points: $\bar{B}^0 \to f_{CP=-1}$ (or $B^0 \to f_{CP=+1}$)

Blue points: $B^0 \to f_{CP=-1}$ (or $\bar{B}^0 \to f_{CP=+1}$)

with fixed $\mathcal{A}_{ccs} = 0$:

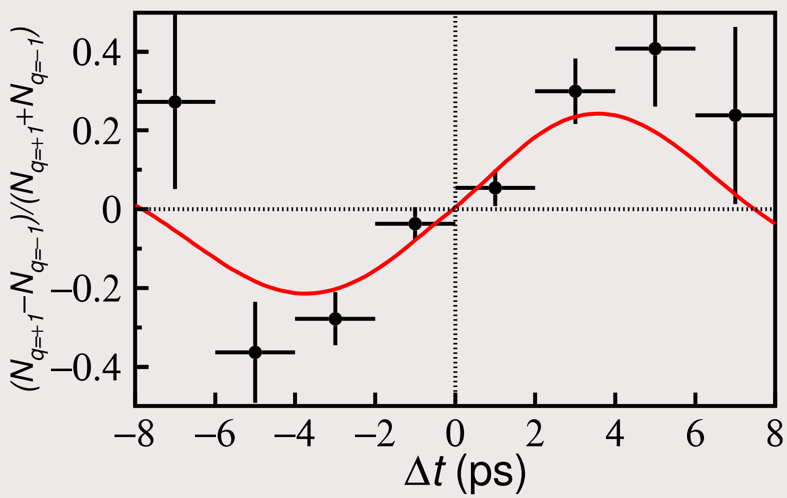
$$-\mathcal{S}_{ccs} = \sin 2\phi_1 = 0.719 \pm 0.074 \pm 0.035$$

with free $\mathcal{A}_{ccs}$ and $\mathcal{S}_{ccs}$:

$$|\lambda_{ccs}| = 0.950 \pm 0.046 \pm 0.026$$

$\mathcal{A}_{ccs}$ is consistent with 0

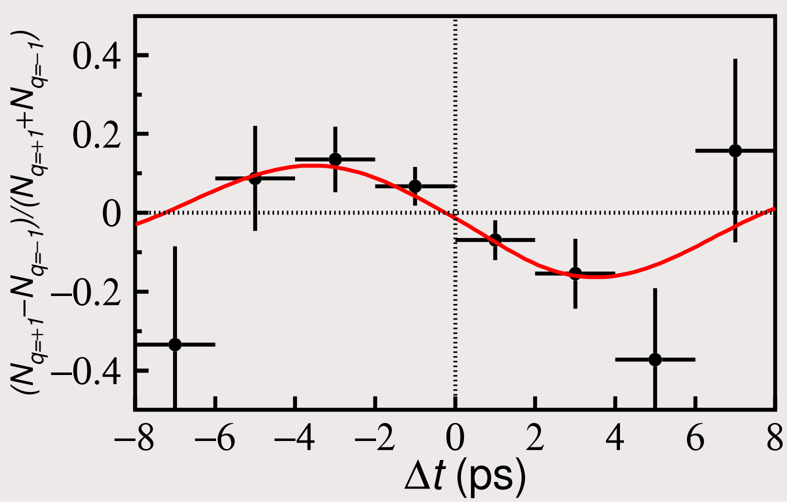
Comparison between $CP = +1$ and $CP = -1$



Since $\mathcal{S}_{ccs} = -\xi_{ccs} \sin 2\phi_1$, $\xi_{ccs} = CP$

$CP = -1$ sample

$$\sin 2\phi_1 = 0.716 \pm 0.083$$



$CP = +1$ sample

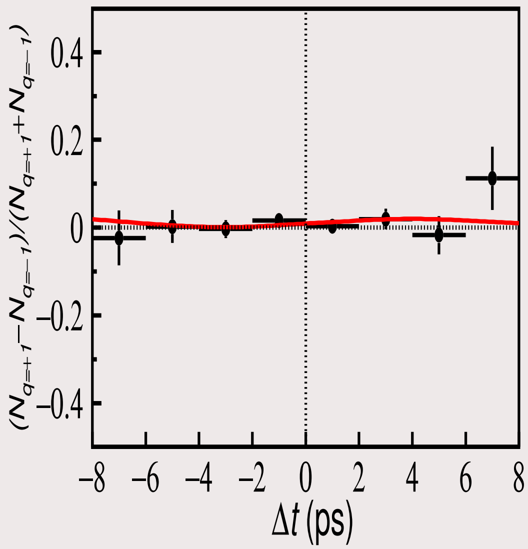
$$\sin 2\phi_1 = 0.78 \pm 0.17$$

N.B. Plotted: raw asymmetry. The amplitude of $\pm \sin 2\phi_1 \sin \Delta m_d \Delta t$ is reduced due to wrong tagging by a factor $(1 - 2w)$.

Checks, systematic errors

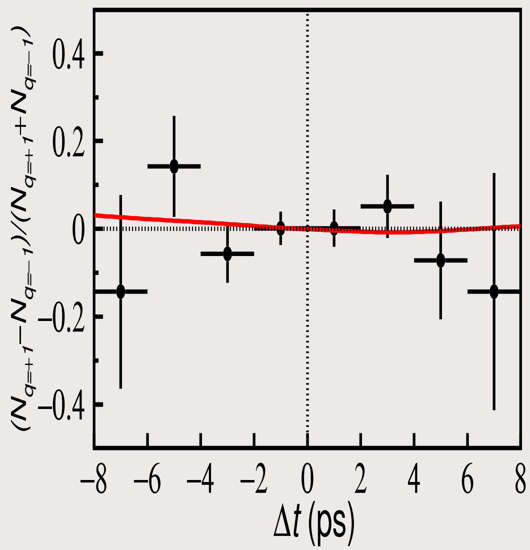
Same analysis for flavour specific final states, where there should be no asymmetry

$B^0 \to D^{*\pm}\pi^{\mp}$



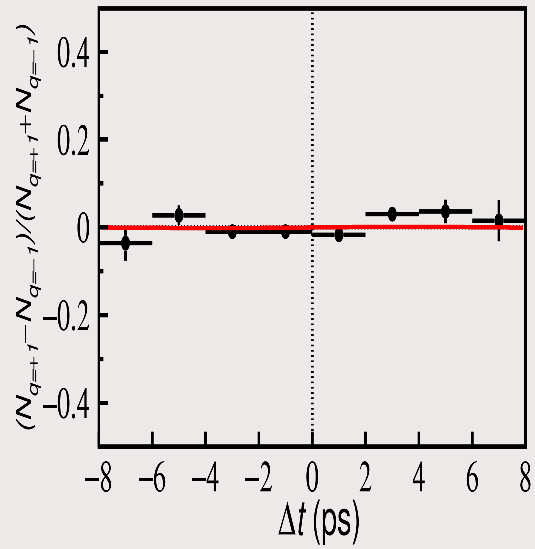
"$\sin 2\phi_1$" $= 0.035 \pm 0.032$

$B^0 \to J/\psi K^{*0},\ K^{*0} \to K^+\pi^-$



"$\sin 2\phi_1$" $= -0.021 \pm 0.093$

$B^0 \to D^*\ell\nu$

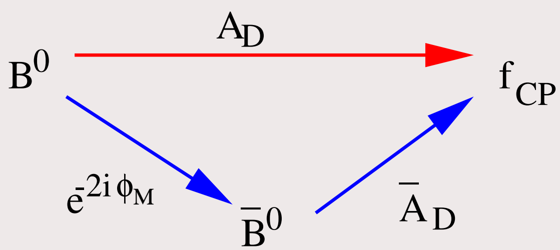


"$\sin 2\phi_1$" $= 0.004 \pm 0.017$

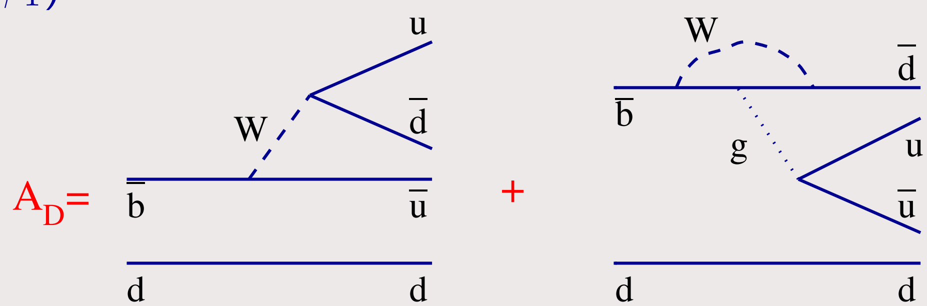
Systematic errors:

vertexing	0.022	resolution function	0.014
possible bias in $\sin 2\phi_1$ fit	0.011	$J/\psi K_L$ background fraction	0.010
Δm_d	< 0.010	τ_B	< 0.010

CP violation in $b \to u\bar{u}d$



Decay amplitude A_D is a sum of a tree process (involving ϕ_2) and a penguin process (involving ϕ_1)



$$\mathcal{S}_{\pi\pi} \sin \Delta m_d \Delta t + \mathcal{A}_{\pi\pi} \cos \Delta m_d \Delta t$$

with

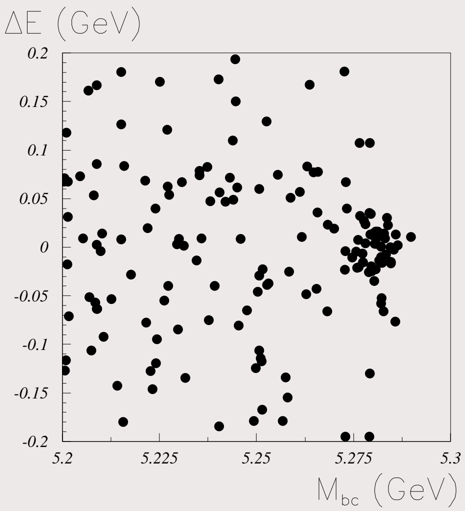
$$\mathcal{S}_{\pi\pi} \neq \sin 2\phi_2$$

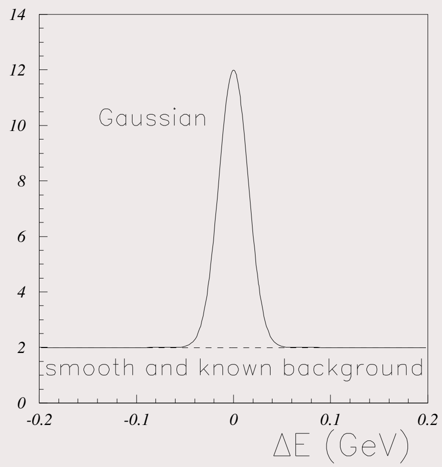
$$\mathcal{A}_{\pi\pi} \neq 0$$

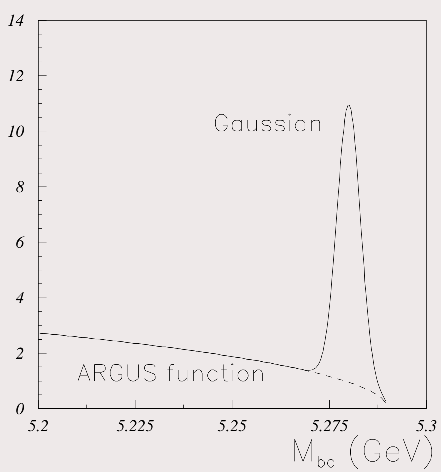
$\to |\lambda_{\pi\pi}| \neq 1$ and $\Gamma(B^0 \to \pi^+\pi^-) \neq \Gamma(\bar{B}^0 \to \pi^+\pi^-)$ (direct CP violation)

B reconstruction method

$BR(B^0 \to \pi^+\pi^-) = (4.4 \pm 0.6 \pm 0.3)10^{-6}$ $\to$ background handling becomes essential!







Two variables (in c.m.s. frame):

- $\Delta E = E(B_{\text{candidate}}) - E_{\text{beam}}$
- $M_{bc} = \sqrt{E^2_{\text{beam}} - \vec{p}^{\,2}_{\text{Bcandidate}}}$

Reconstruction of $B^0 \to \pi^+\pi^-$

Data sample 78 fb^{-1}

Signal region:

- ✦ $5.271\text{GeV}/c^2 < M_{bc} < 5.287\text{GeV}/c^2$
- ✦ $|\Delta E| < 0.057$ GeV

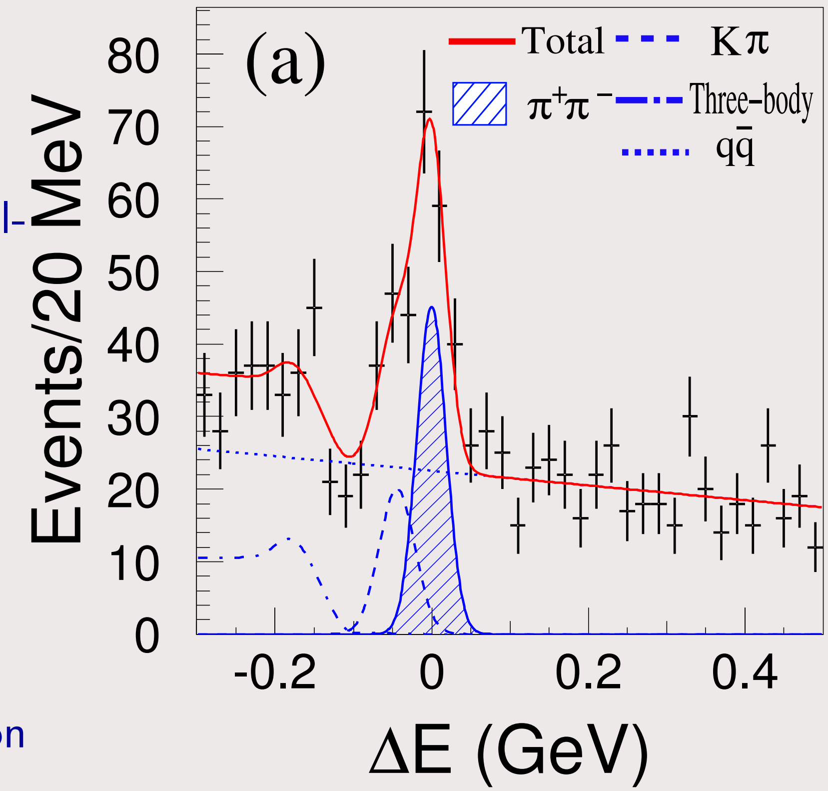
corresponding to $\pm 3\sigma$ from the central values.

$$N(\pi\pi) = 106^{+16}_{-15} \ \text{events}$$

$$41^{+10}_{-9}\ K\pi \ \text{feed}-\text{across}$$

$$128^{+5}_{-6}\ \text{continuum events}$$

for events with the continuum suppression variable cut at $LR > 0.825$



ΔE distribution after M_{bc} cut

Reconstruction of $B^0 \to \pi^+\pi^-$, relaxed criteria

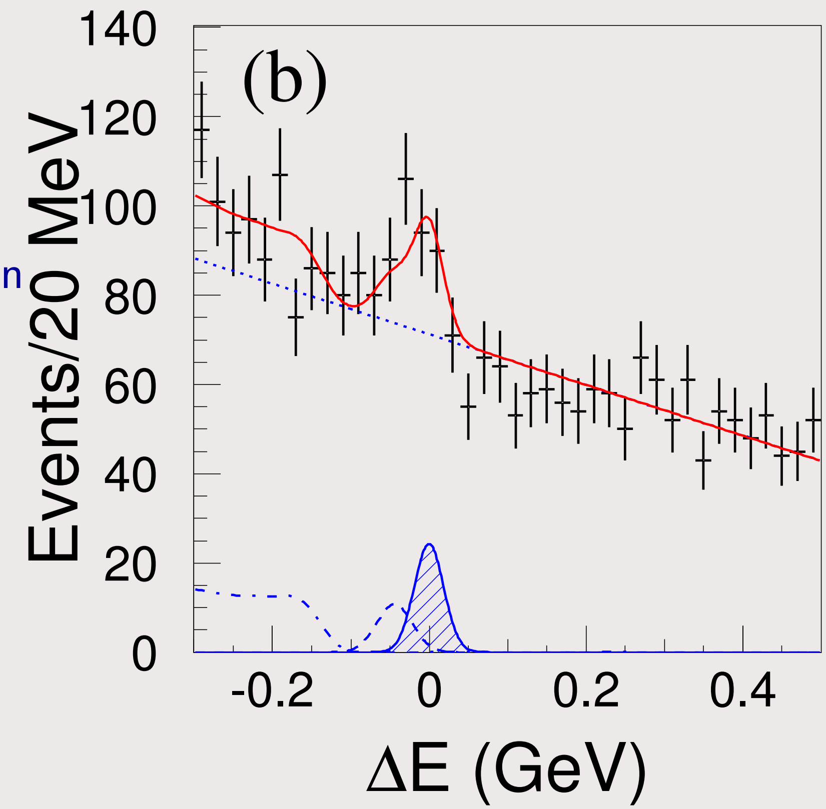
Signal region 2:

- $5.271\text{GeV}/c^2 < M_{bc} < 5.287\text{GeV}/c^2$
- $|\Delta E| < 0.057$ GeV
- $+$ events with a continuum suppression variable $0.425(0.325) < LR < 0.825$

$$N(\pi\pi) = 106^{+16}_{-15} \quad \text{events}$$

$$41^{+10}_{-9} \; K\pi \text{ feed} - \text{across}$$

$$128^{+5}_{-6} \text{ continuum events}$$



ΔE distribution after M_{bc} cut

Fitting for $\mathcal{S}_{\pi\pi}$ and $\mathcal{A}_{\pi\pi}$

Likelihood for event i:

$$
\begin{aligned}
P_i = (1-f_{ol})\int_{-\infty}^{+\infty}\{(f^m_{\pi\pi}\mathcal{P}^q_{\pi\pi}(\Delta t', w_l; \mathcal{A}_{\pi\pi}, \mathcal{S}_{\pi\pi}) \\
+f^m_{K\pi}\mathcal{P}^q_{K\pi}(\Delta t', w_l))\cdot R_{sig}(\Delta t_i - \Delta t') \\
+f^m_{q\overline{q}}\mathcal{P}_{q\overline{q}}(\Delta t')\cdot R_{q\overline{q}}(\Delta t_i - \Delta t')\}d\Delta t' + f_{ol}\mathcal{P}_{ol}(\Delta t_i).
\end{aligned} \quad (1)
$$

$$\mathcal{P}^q_{\pi\pi} = \frac{e^{-|\Delta t|/\tau_{B0}}}{4\tau_{B0}}\left[1 + q\cdot\{\mathcal{S}_{\pi\pi}\sin(\Delta m_d \Delta t) \ \ +\mathcal{A}_{\pi\pi}\cos(\Delta m_d\Delta t)\}\right],$$

$$\mathcal{P}^q_{K\pi}(\Delta t, w_l) = e^{-|\Delta t|/\tau_{B^0}}/(4\tau_{B^0})\{1 + q\cdot(1-2w_l)\cdot\mathcal{A}_{K\pi}\cdot\cos(\Delta m_d\Delta t)\},$$

$$\mathcal{P}_{q\overline{q}}(\Delta t) = (1 + q\cdot\mathcal{A}_{\rm bkg})/2\{f_\tau e^{-|\Delta t|/\tau_{\rm bkg}}/(2\tau_{\rm bkg}) + (1-f_\tau)\delta(\Delta t)\}$$

with $f_\tau = 0.014^{+0.006}_{-0.004}$ = fraction of the background with effective lifetime $\tau_{\rm bkg} = 2.37^{+0.44}_{-0.34}$ ps, determined from the events in the $q\overline{q}$-background-dominated sideband region.

Probability functions f^m_k ($k = \pi\pi$, $K\pi$ or $q\overline{q}$) are determined on an event-by-event basis as functions of ΔE and $M_{\rm bc}$ for each LR-r interval.

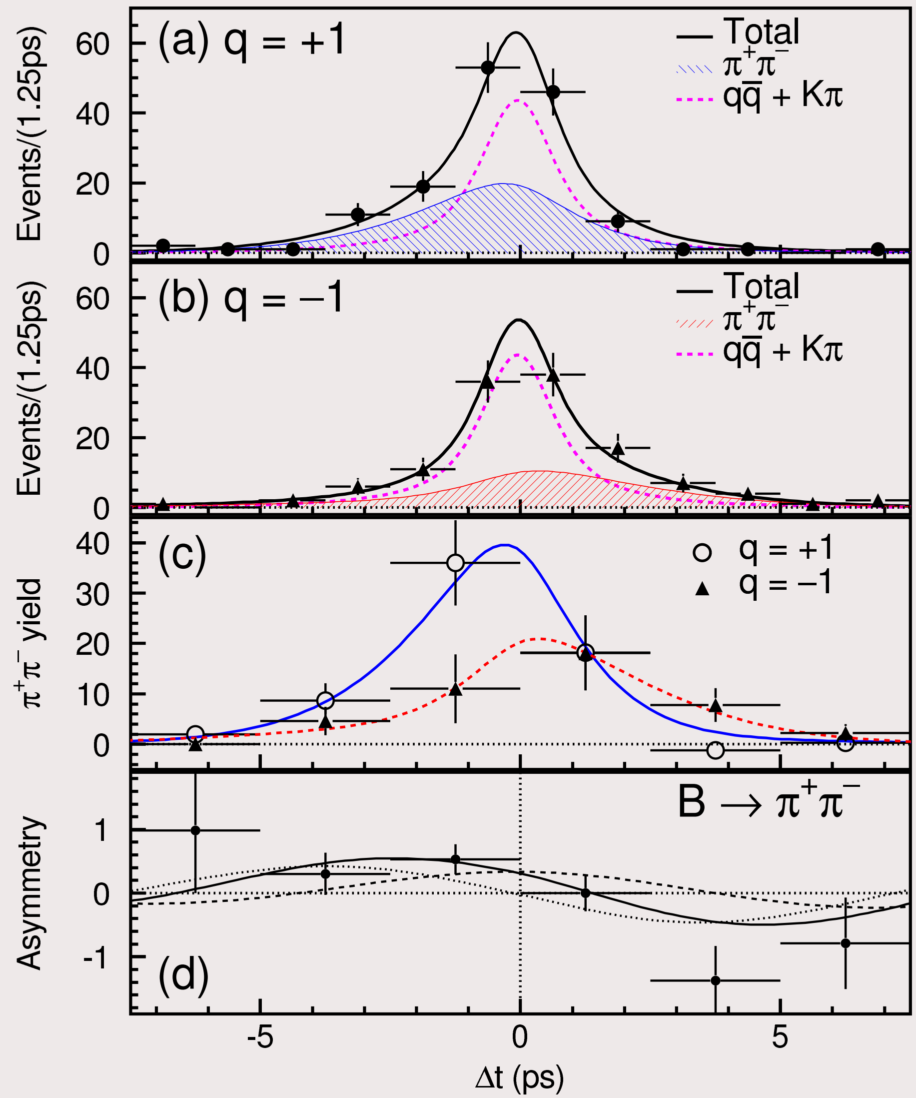
CP violation: $\mathcal{S}_{\pi\pi}$ and $\mathcal{A}_{\pi\pi}$

The event-by-event max. likelihood fit in Δt yields:

$\mathcal{A}_{\pi\pi} =$
$= +0.77 \pm 0.27(\mathrm{stat}) \pm 0.08(\mathrm{syst})$

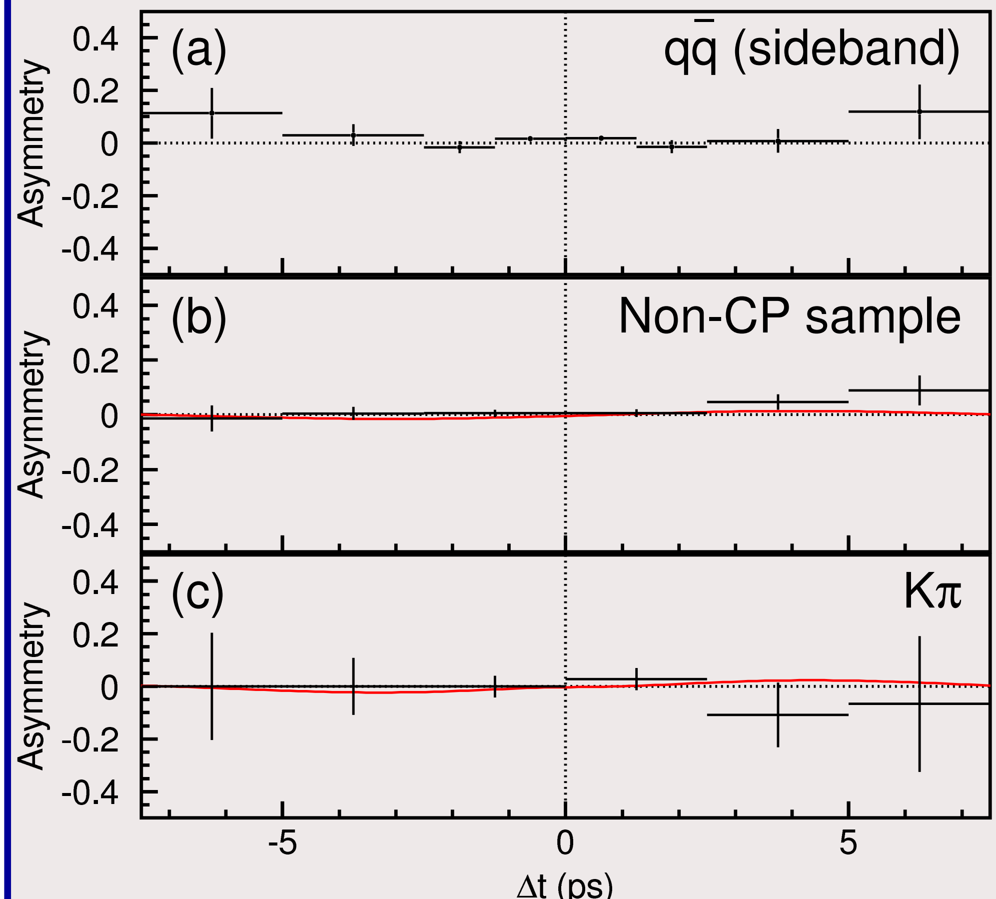
and

$\mathcal{S}_{\pi\pi} =$
$= -1.23 \pm 0.41(\mathrm{stat})\ ^{+0.08}_{-0.07}(\mathrm{syst}),$



Checks

The distributions of the raw Δt asymmetries for processes where no asymmetry is expected



(a) $B^0 \to \pi^+\pi^-$ sideband events,

(b) the $B^0 \to D^-\pi^+$, $D^{*-}\pi^+$ and $D^{*-}\rho^+$ candidates combined,

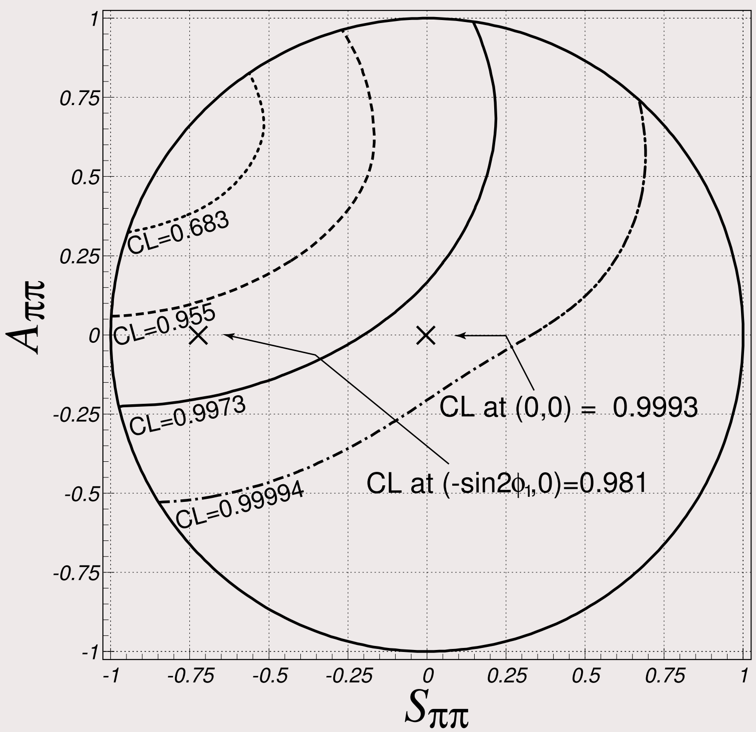
(c) $B^0 \to K^+\pi^-$ candidates.

$\longrightarrow$ consistent with zero asymmetry

Systematic errors in $\mathcal{S}_{\pi\pi}$ and $\mathcal{A}_{\pi\pi}$

	$\mathcal{A}_{\pi\pi}$		$\mathcal{S}_{\pi\pi}$	
Source	+error	−error	+error	−error
Background fractions	+0.058	−0.048	+0.044	−0.055
Vertexing	+0.044	−0.054	+0.037	−0.012
Fit bias	+0.016	−0.021	+0.052	−0.020
Wrong tag fraction	+0.026	−0.021	+0.015	−0.016
Physics (τ_{B^0}, Δm_d, $\mathcal{A}_{K\pi}$)	+0.021	−0.014	+0.022	−0.022
Resolution function	+0.019	−0.020	+0.010	−0.013
Background shape	+0.003	−0.015	+0.007	−0.002
Total	+0.084	−0.083	+0.083	−0.067

Significance of $\mathcal{S}_{\pi\pi}$ and $\mathcal{A}_{\pi\pi}$



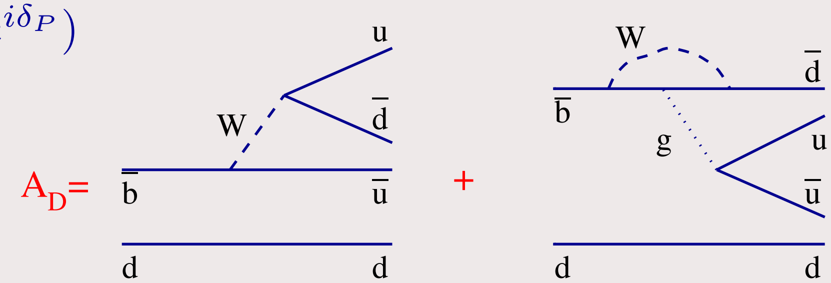
Confidence regions for $\mathcal{A}_{\pi\pi}$ and $\mathcal{S}_{\pi\pi}$.

- $\mathcal{A}_{\pi\pi} = 0$, $\mathcal{S}_{\pi\pi} = 0$ is excluded with 99.93% CL (3.4 σ)
- $\mathcal{A}_{\pi\pi} > 0$ (=direct CP violation): observation, for evidence need more statistics
- "superweak" scenario ($\mathcal{S}_{\pi\pi} = -\sin 2\phi_2, \mathcal{A}_{\pi\pi} = 0$) excluded at 2.3 σ

Constraints on the CKM angle ϕ_2

Decay amplitudes:

$$A_D(B^0 \to \pi^+\pi^-) = -(|T|e^{i\delta_T}e^{i\phi_3} + |P|e^{i\delta_P})$$
$$A_D(B^0 \to \pi^+\pi^-) = -(|T|e^{i\delta_T}e^{i\phi_3} + |P|e^{i\delta_P})$$
$$\lambda_{\pi\pi} = e^{-2i\phi_2}\frac{1+|P/T|e^{i(\delta+\phi_3)}}{1+|P/T|e^{i(\delta-\phi_3)}}$$

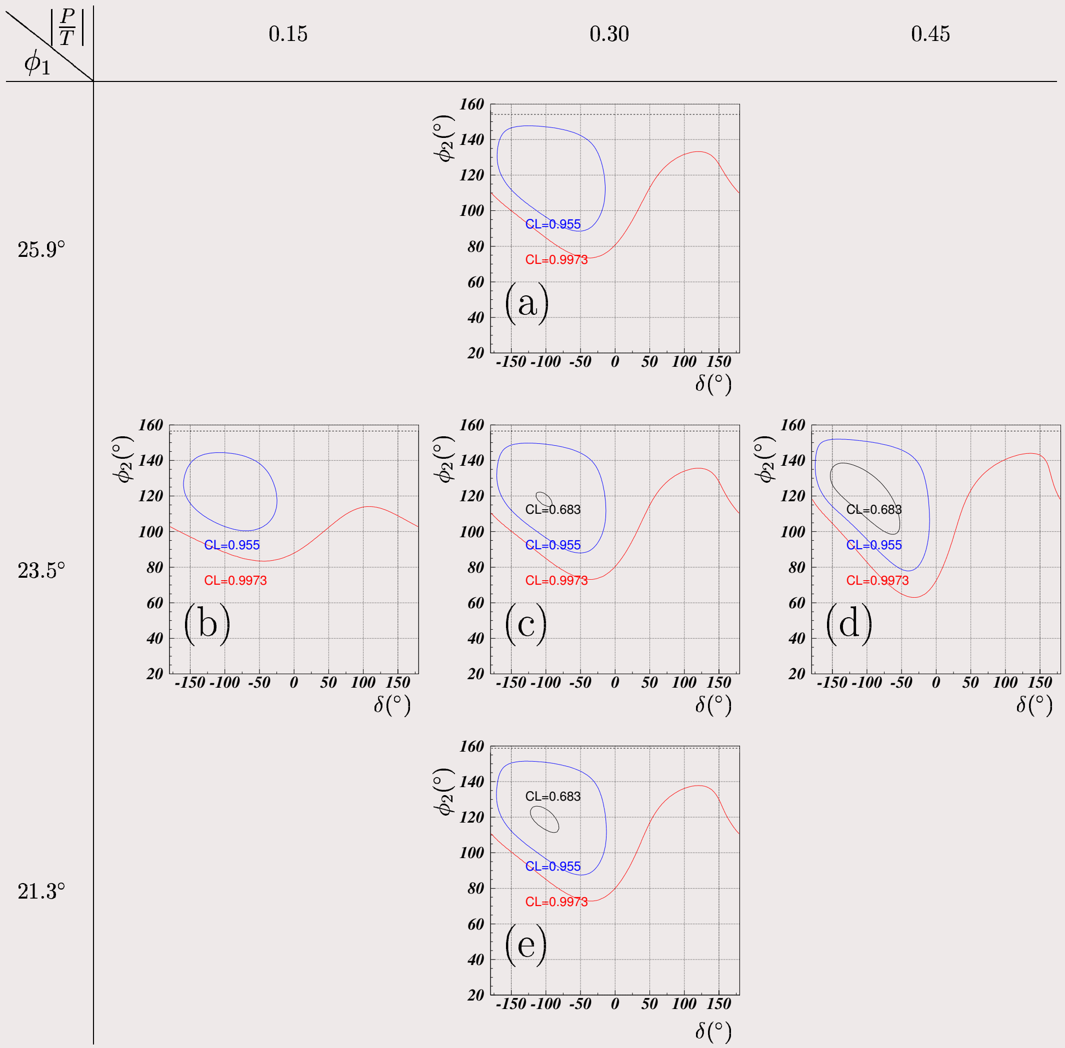


$$\mathcal{S}_{\pi\pi} = [\sin 2\phi_2 + 2|P/T|\sin(\phi_1-\phi_2)\cos\delta - |P/T|^2\sin 2\phi_1]/R_{\pi\pi}$$
$$\mathcal{A}_{\pi\pi} = -[2|P/T|\sin(\phi_1+\phi_2)\sin\delta]/R_{\pi\pi}$$

with $R_{\pi\pi} = 1 - 2|P/T|\cos(\phi_1+\phi_2)\cos\delta + |P/T|^2$, $\delta = \delta_P - \delta_T$

$|P/T|$ between 0.15 and 0.45 (Gronau+Rosner 0.276 ± 0.064)
ϕ_1 between 21.3^0 and 25.9^0 (Belle+BaBar combined)

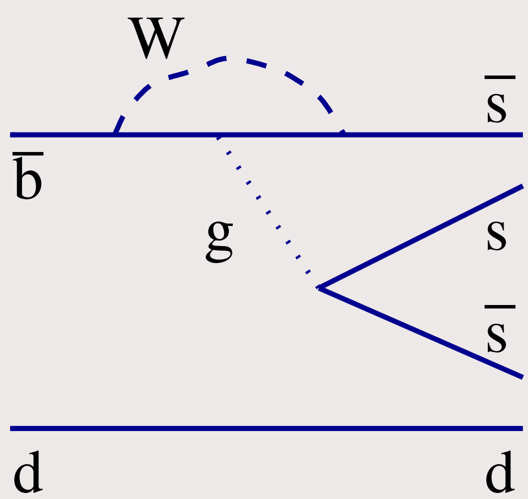
Constraints on the CKM angle ϕ_2



$78^0 < \phi_2 < 152^0$

(at 95.5% C.L.)

CP violation in $b \longrightarrow s\bar{s}s$



Standard Model:

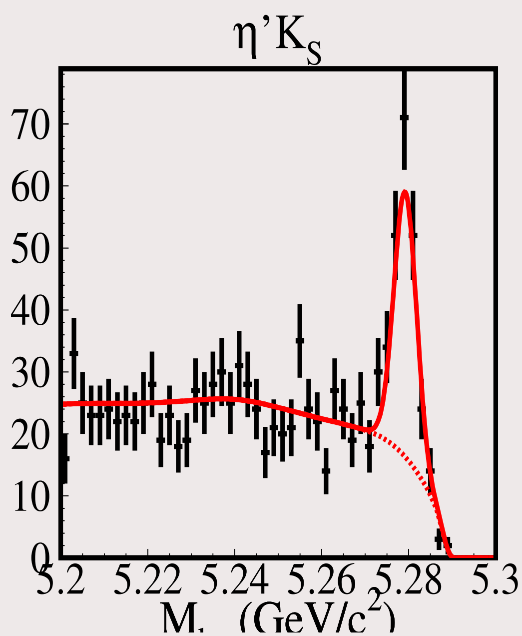
- $\mathcal{S}_{sss} = -\xi_f \sin 2\phi_1 \; (b \longrightarrow c\bar{c}s)$
- $\mathcal{A}_{sss} \approx 0$

$\xi_f = CP$ eigenvalue for the f_{CP}

$B^0 \to \eta' K_S,\ \phi K_S,\ K^+K^-K_S$

$B^0 \to \eta' K_S$

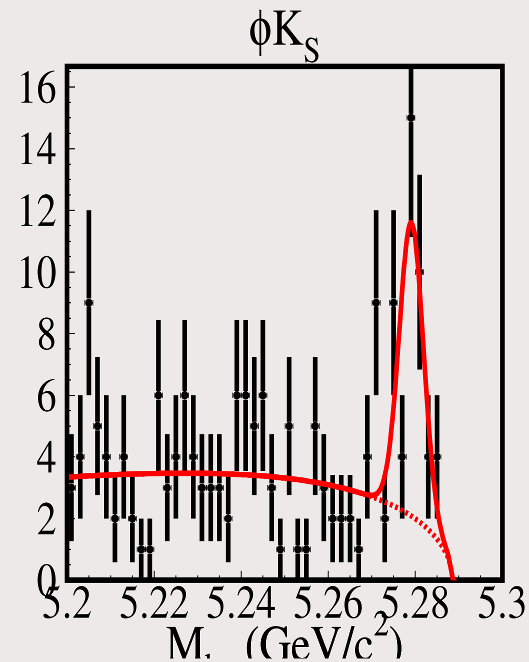
$\eta' \to \pi^+\pi - \eta, \rho\gamma,\ \eta \to \gamma\gamma$



$N(B^0 \to \eta' K_S) = 147.9 \pm 14.6$

$B^0 \to \phi K_S$

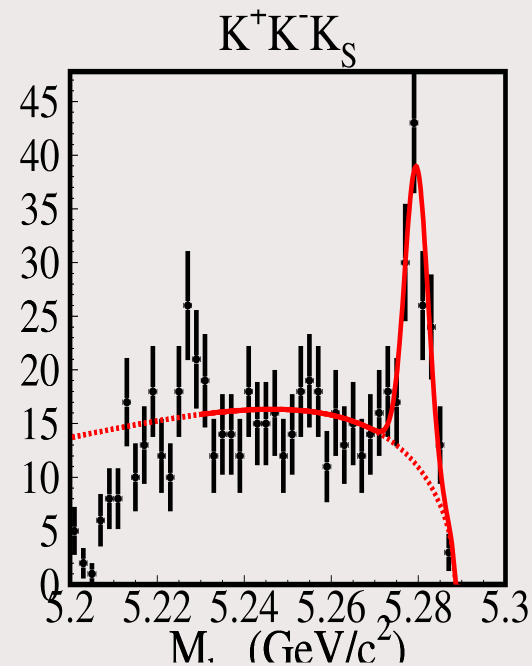
$\phi \to K^+K^-,\ K_S \to \pi^+\pi^-$



$N(B^0 \to \phi K_S) = 35.4 \pm 2.9$

$B^0 \to K^+K^-K_S$

$K^+K^- \neq \phi,\ K_S \to \pi^+\pi^-$



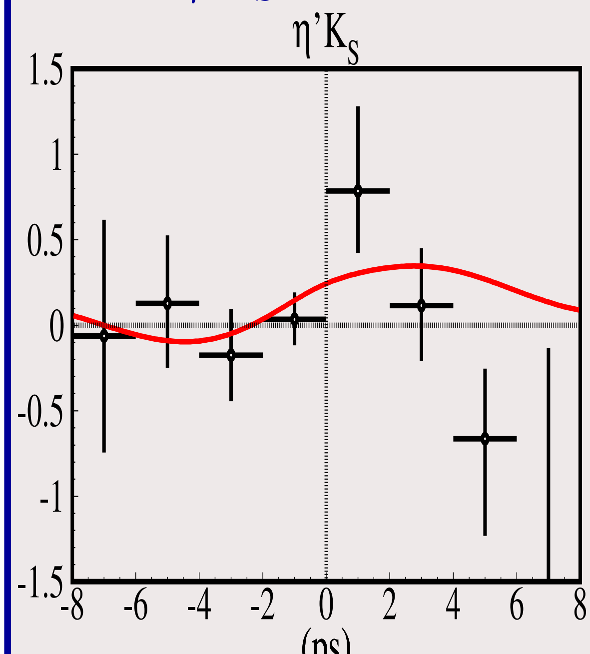
$N(B^0 \to K^+K^-K_S) = = 94.3 \pm 7.3$

data sample 78 fb^{-1}

CP violation in $b \to s\bar{s}s$ - results

Raw asymmetries

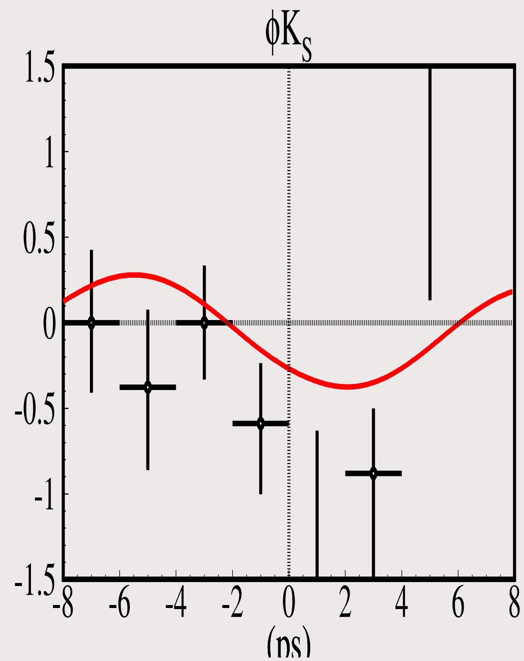
$B^0 \to \eta' K_S$



$\mathcal{S}_{\eta' K} = 0.76 \pm 0.36^{+0.05}_{-0.06}$

$\mathcal{A}_{\eta' K} = +0.26 \pm 0.22 \pm 0.03$

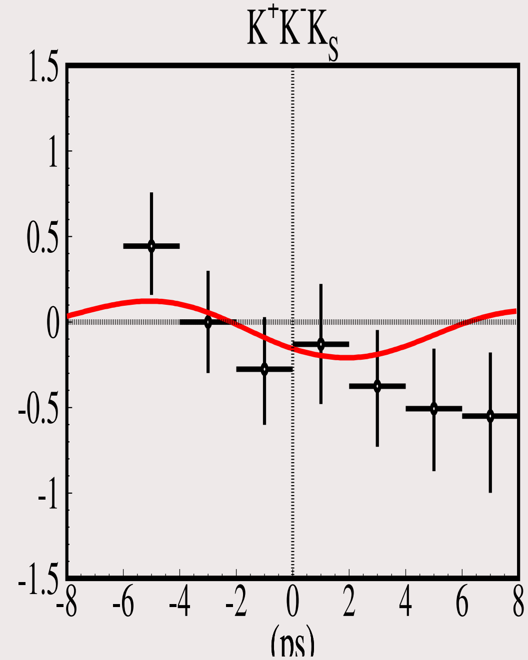
$B^0 \to \phi K_S$



$\mathcal{S}_{\phi K} = -0.73 \pm 0.64 \pm 0.18$

$\mathcal{A}_{\phi K} = -0.56 \pm 0.41 \pm 0.12$

$B^0 \to K^+K^-K_S$



$-\mathcal{S}_{KKK} =$
$= 0.52 \pm 0.46 \pm 0.11^{+0.27}_{-0.03}$

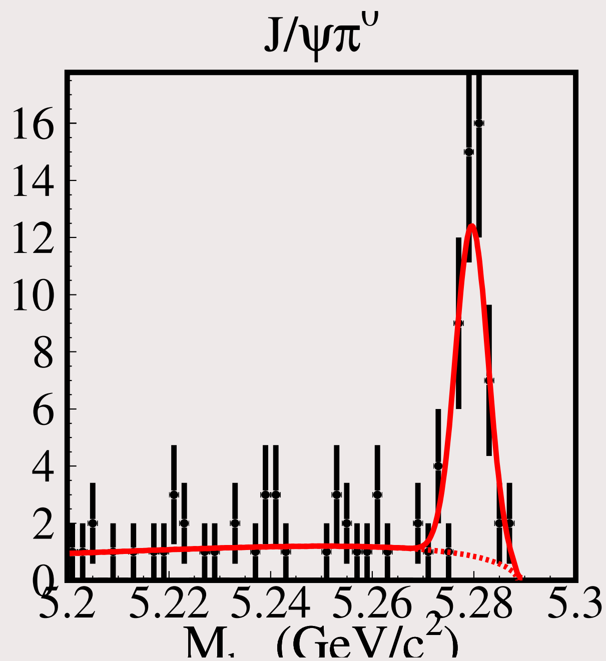
$\mathcal{A}_{KKK} =$
$= -0.42 \pm 0.36 \pm 0.09^{+0.03}_{-0.22}$

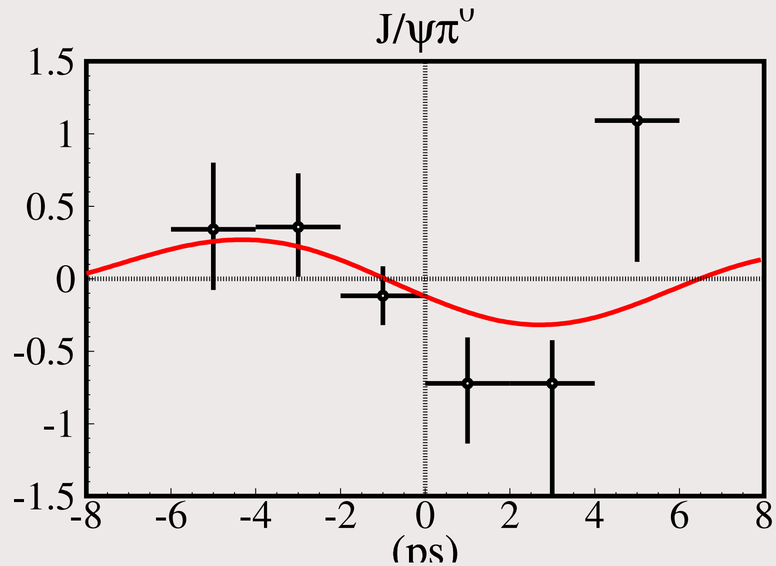
last error: uncert. in $CP\pm$ fractions, $w = (3^{+16}_{-3})\%$

to be compared with $\mathcal{S}_{ccs} = 0.719 \pm 0.074 \pm 0.035$

CP violation in $B^0 \to J/\psi\pi^0$

$B^0 \to J/\psi\pi^0$ is a $b \to c\bar{c}d$ transition to a $CP = +1$ eigenstate.





$$-\mathcal{S}_{J/\psi\pi} = +0.93 \pm 0.49 \pm 0.08$$

$$N(J/\psi\pi^0) = 49.1 \pm 1.3$$

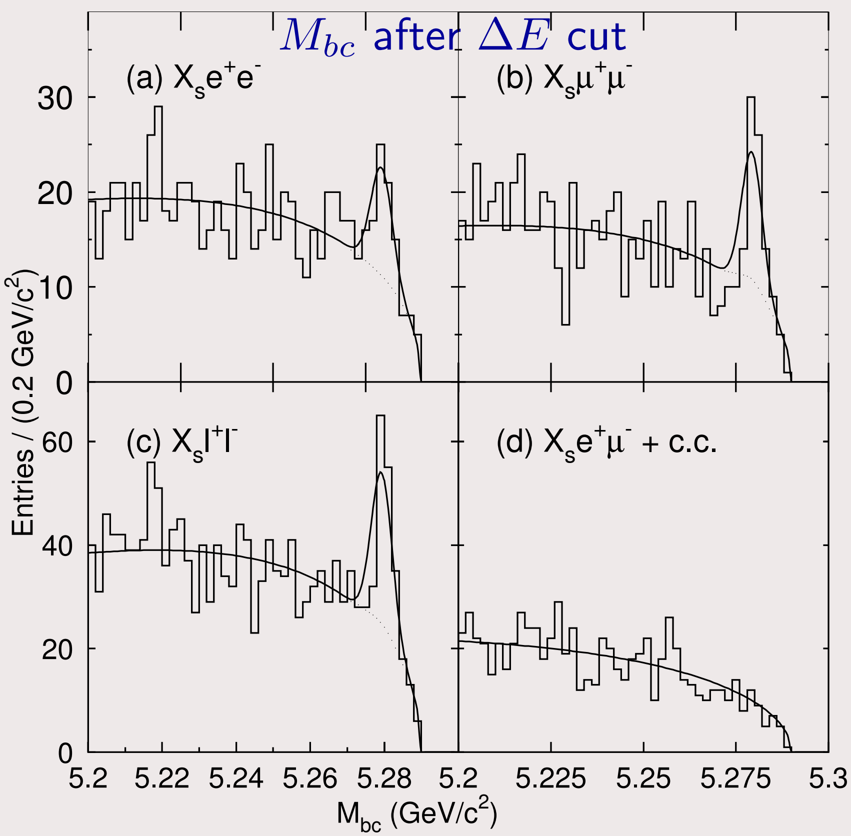
$$\mathcal{A}_{J/\psi\pi} = -0.25 \pm 0.39 \pm 0.06$$

data sample 78 fb^{-1}

Measurement of $B \to X_s \ell^+ \ell^-$

- Flavour changing neutral current (FCNC) process $b \to s\ell\ell$ was first measured in $B \to K\ell\ell$ by Belle
- Inclusive $b \to s\ell\ell$ measurement is a model independent probe for new physics

Inclusive measurement: pseudo-reconstruction of $B \to X_s \ell^+ \ell^-$,
for X_s use $K^\pm$ or K_S with 0-4 π (0 or 1 π^0) - accounts for 78% of $b \to s\ell\ell$

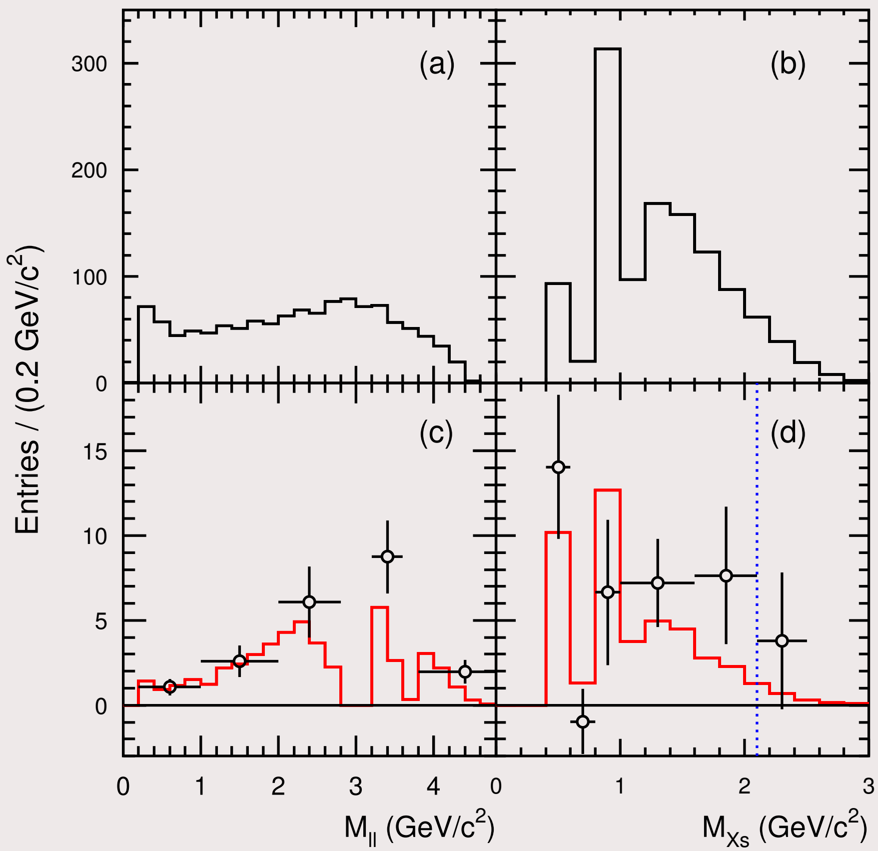


- background from $B \to X_s J/\psi (\to \ell^+\ell^-)$, $X_s \psi(2S) (\to \ell^+\ell^-)$ removed by $M_{\ell\ell}$ veto
- contamination from $B \to X_s \pi^+ \pi^-$ (4.5 events for $\mu\mu$, 0.2 for ee) is subtracted

data sample 60 fb^{-1}

$M_{\ell\ell}$ and $M(X_s)$ distributions

$BR(B \to X_s \ell^+ \ell^-) = (6.1 \pm 1.4^{+1.3}_{-1.1}) \cdot 10^{-6}$ for $M_{\ell\ell} > 0.2$ GeV/c^2

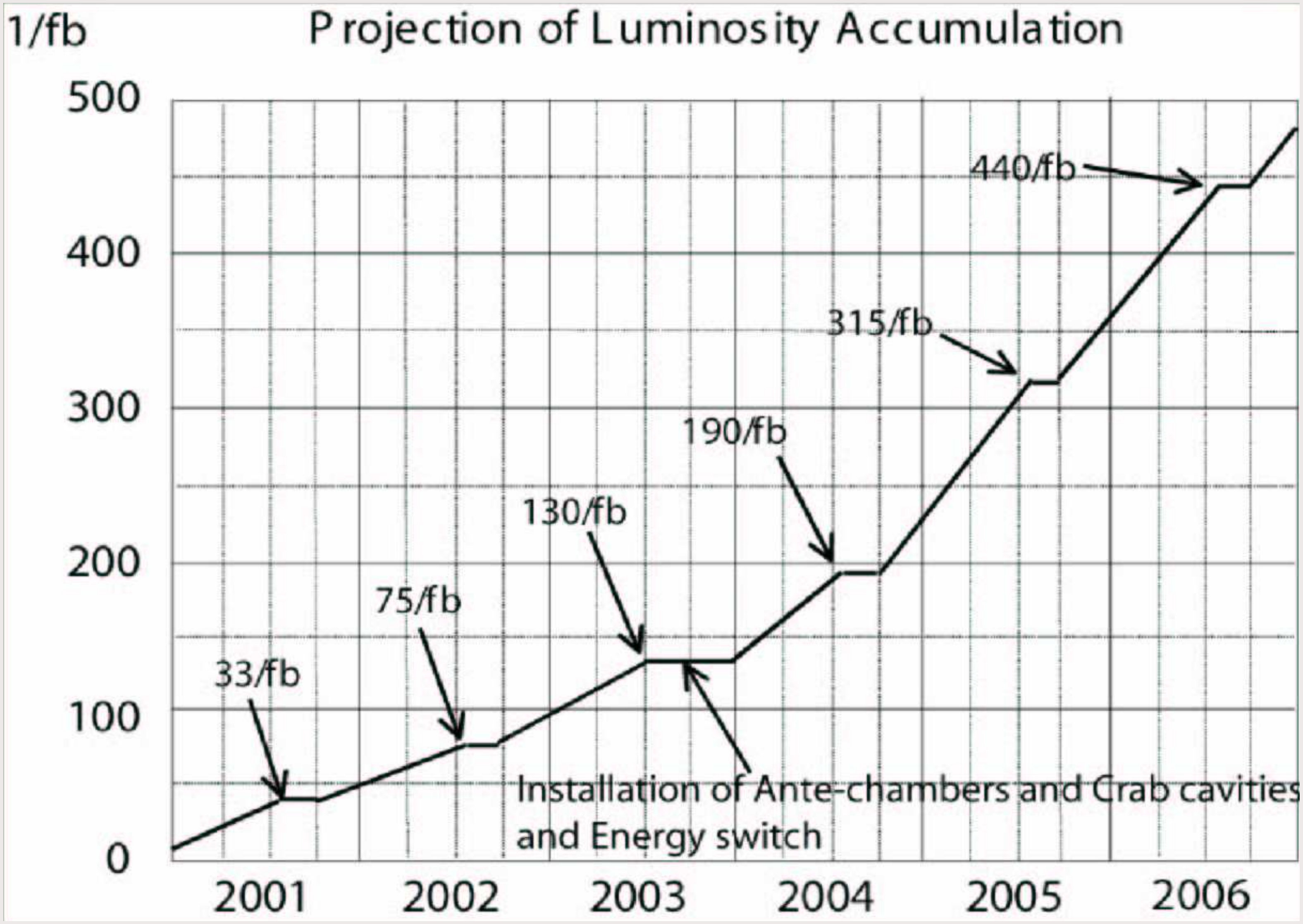


mass spectra assumed in MC (SM calculation, model by A. Ali et al.)

observed spectra with eff. corrected predictions

In K and K^* regions consistent with exclusive measurements.

What comes next?



Spectrometer upgrades I

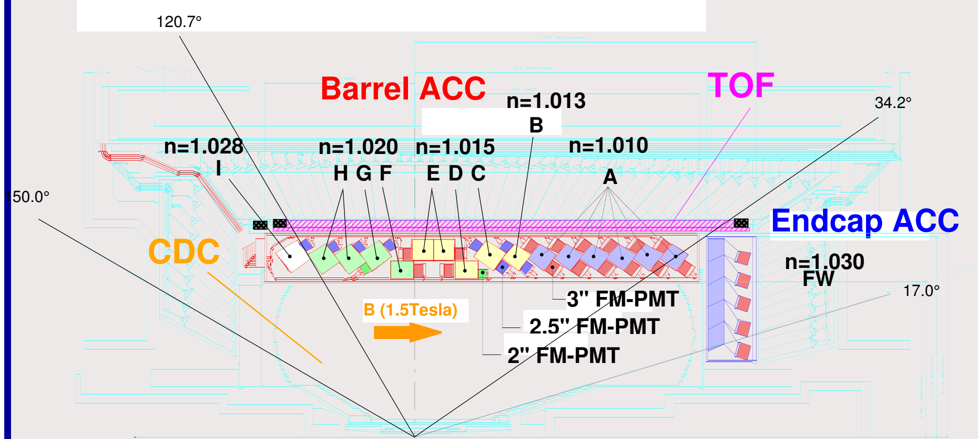
Upgrade of the silicon vertex detector

- $3 \longrightarrow 4$ detector planes
- better radiation hardness of the read-out electronics (0.35 μm technology)
- to be included in early trigger stages

The detector is ready, tested with cosmics, waiting for the summer shut-down for installation

Spectrometer upgrades II

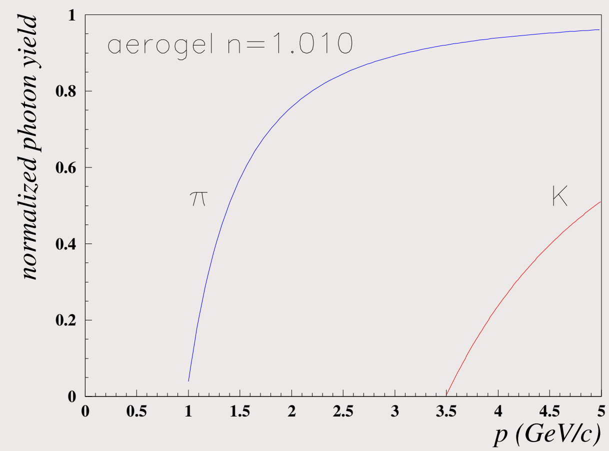
Present particle ID: one of the main components is the aerogel threshold Čerenkov counter (ACC) Separation of K (below) vs. π (above thr.): properly choosing n for a given kinematic region



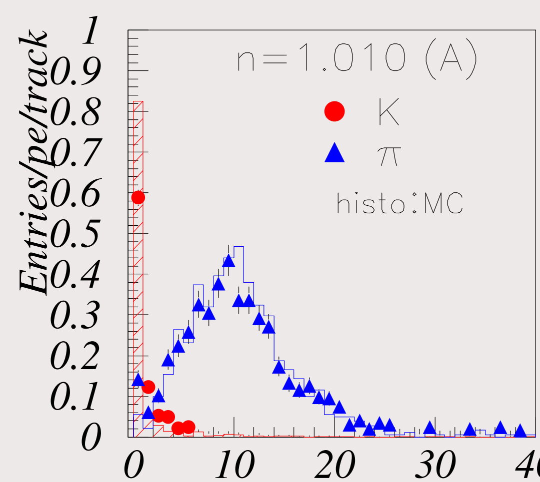
Barrel: covers both tagging and $B \to \pi\pi, K\pi$

Forward: tagging only

expected average yield vs p

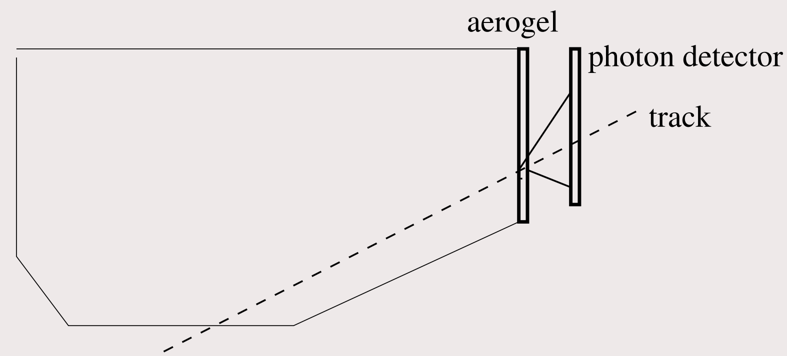


measured for 2 GeV/c< p <3.5 GeV/c



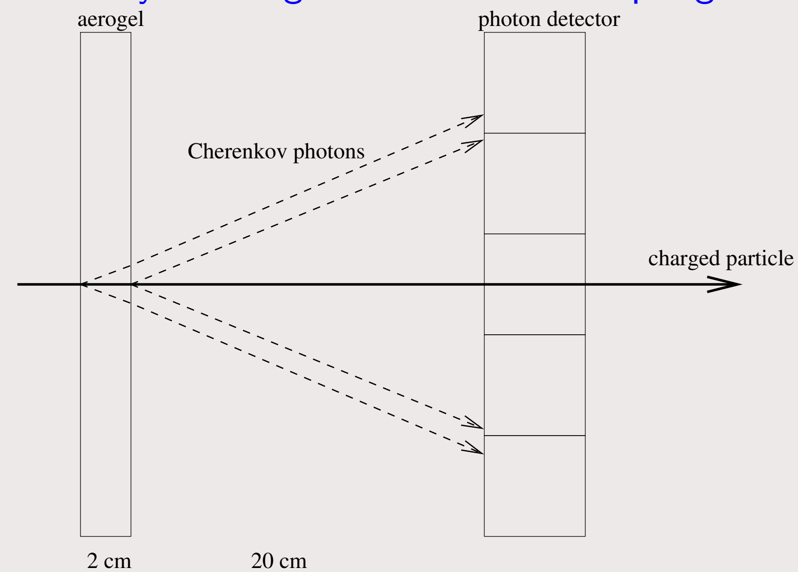
Spectrometer upgrades II - continued

Improve particle identification in the forward direction (due to considerable boost, only tagging K can be covered by the threshold aerogel Čerenkov counter): two-body decay products have momenta of up to 4 GeV/c



Proximity focusing RICH in the end-cap region

Under study: proximity focusing Čerenkov counter with aerogel as radiator



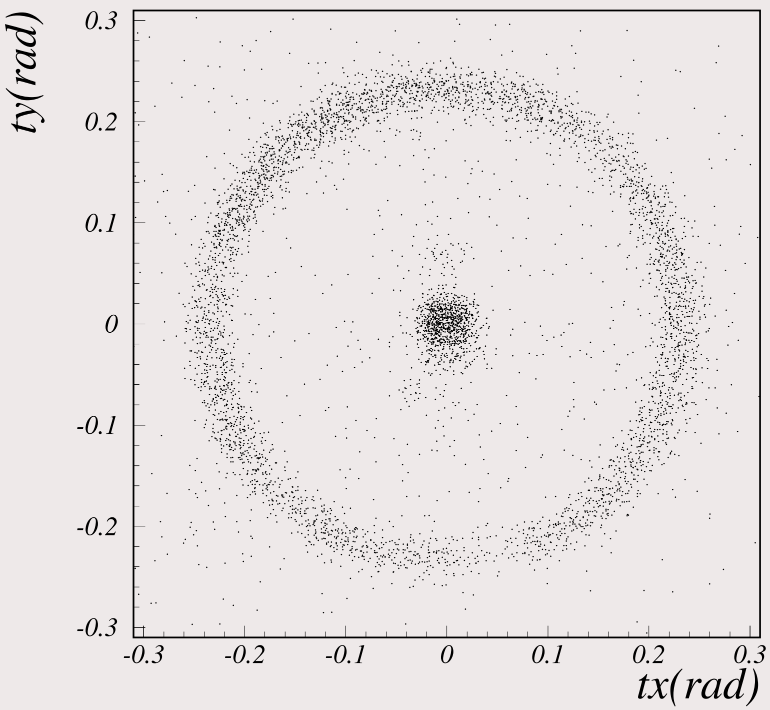
Proximity focusing RICH - principle

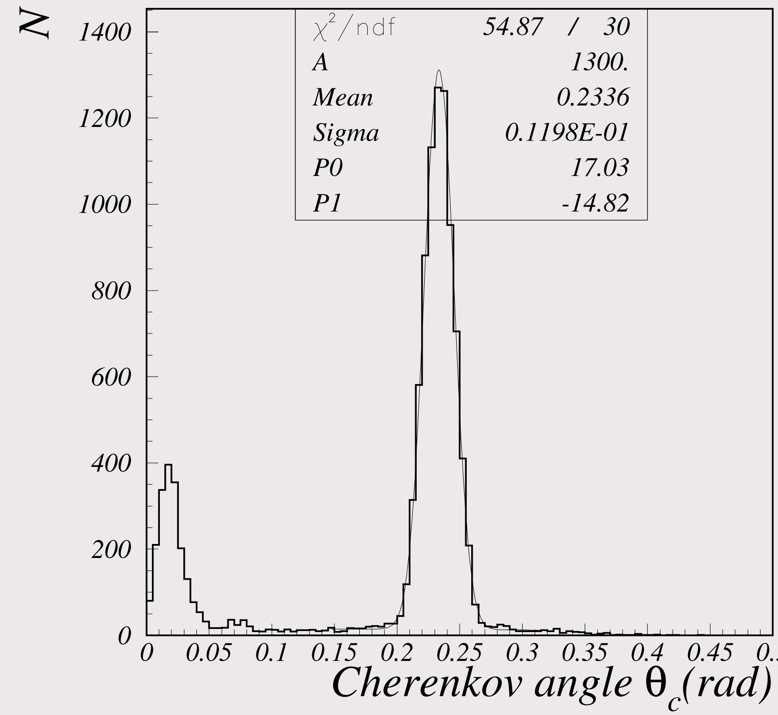
Aerogel as radiator:
n=1.05: $\theta_c(\pi) = 310$ mrad,
$\theta_c(\pi) - \theta_c(K) = 23$ mrad at 4 GeV/c
number of photons in 2 cm of aerogel: 17
($N_0 = 90$/cm, no absorption)

Spectrometer upgrades II - continued

Beam test results

accumulated hits on the photon detector





very clean Čerenkov angle distribution

Typically, 6 photons per $\beta = 1$ track are detected on average, $\rightarrow$ 8 seems within reach.

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Summary

- Belle has accumulated ¿130 fb^{-1} of data at the KEKB asymmetric B factory
- Current results are based on 89.6 fb^{-1} of data (78 fb^{-1} on $\Upsilon(4S)$, 85 M $B\bar{B}$ pairs)
- CP violating parameters are measured to be

$$\mathcal{S}_{ccs} = 0.719 \pm 0.074 \pm 0.035,\ |\lambda_{ccs}| = 0.950 \pm 0.046 \pm 0.026$$

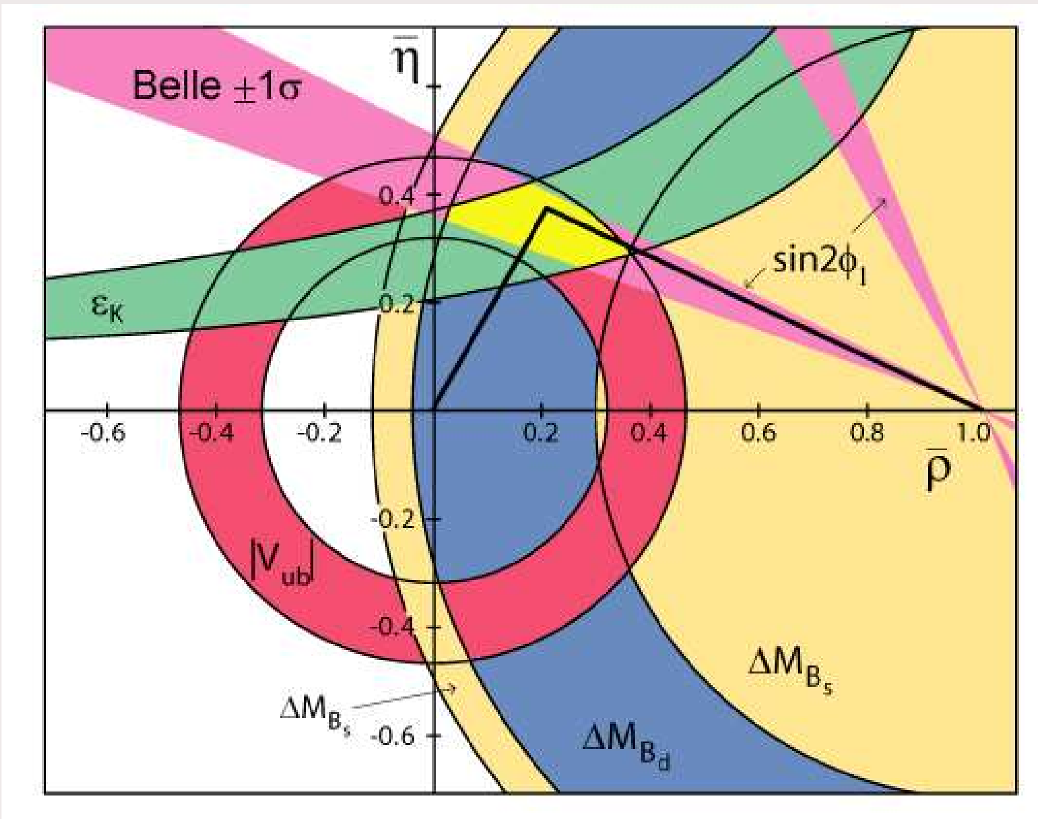
$$\mathcal{S}_{\pi\pi} = -1.21^{+0.38+0.16}_{-0.27-0.13},\ \mathcal{A}_{\pi\pi} = +0.94^{+0.25}_{-0.31} \pm 0.09$$

- Time dependent CP violation was measured in $b \to s\bar{s}s$ and $b \to c\bar{c}d$
- Inclusive $b \to s\ell\ell$ was measured by pseudo-reconstruction:

$$BR(B \to X_s \ell^+ \ell^-) = (6.1 \pm 1.4^{+1.3}_{-1.1}) \cdot 10^{-6}$$

- Upgrades are either ready or being prepared to make the spectrometer even more precise and efficient.
- The next generation B-factory (SuperKEKB) is being considered.

$\rho - \eta$ plane



- ✦ Triangle: as determined from other measurements (PDG2002 compilation)
- ✦ Belle: present result on $\sin 2\phi_1$