Physics at B-factories

Part 2: Measurements of the angles and sides of the unitarity triangle

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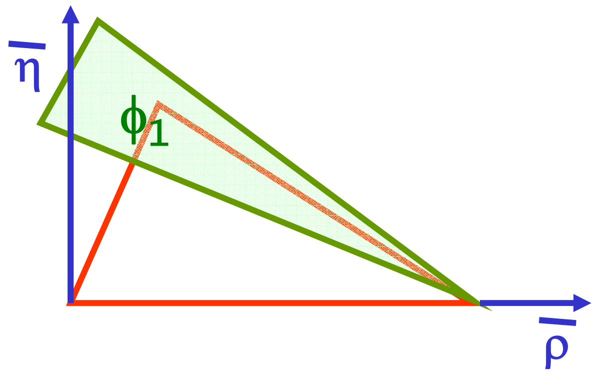
BELLE

How to measure sin2ϕ_1?



To measure sin2ϕ_1, we have to measure the time dependent CP asymmetry in $B^0 \rightarrow J/\Psi K_s$ decays

$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t) = \sin 2\phi_1 \sin(\Delta m t)$$

$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}$$

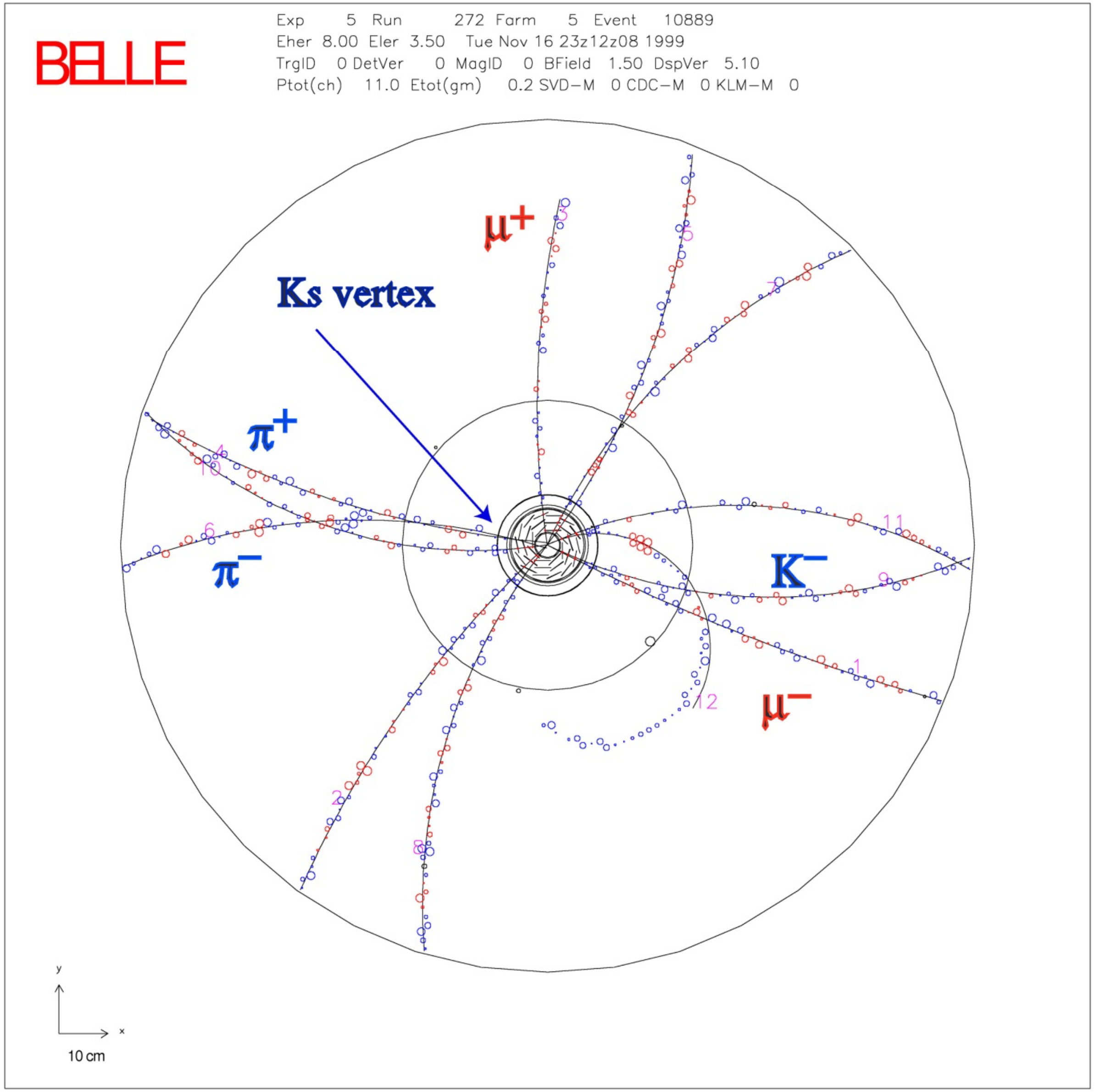
Reconstructing chamonium states

Reconstructing final states X which decayed to several particles (x,y,z):
From the measured tracks calculate the invariant mass of the system (i=x,y,z):

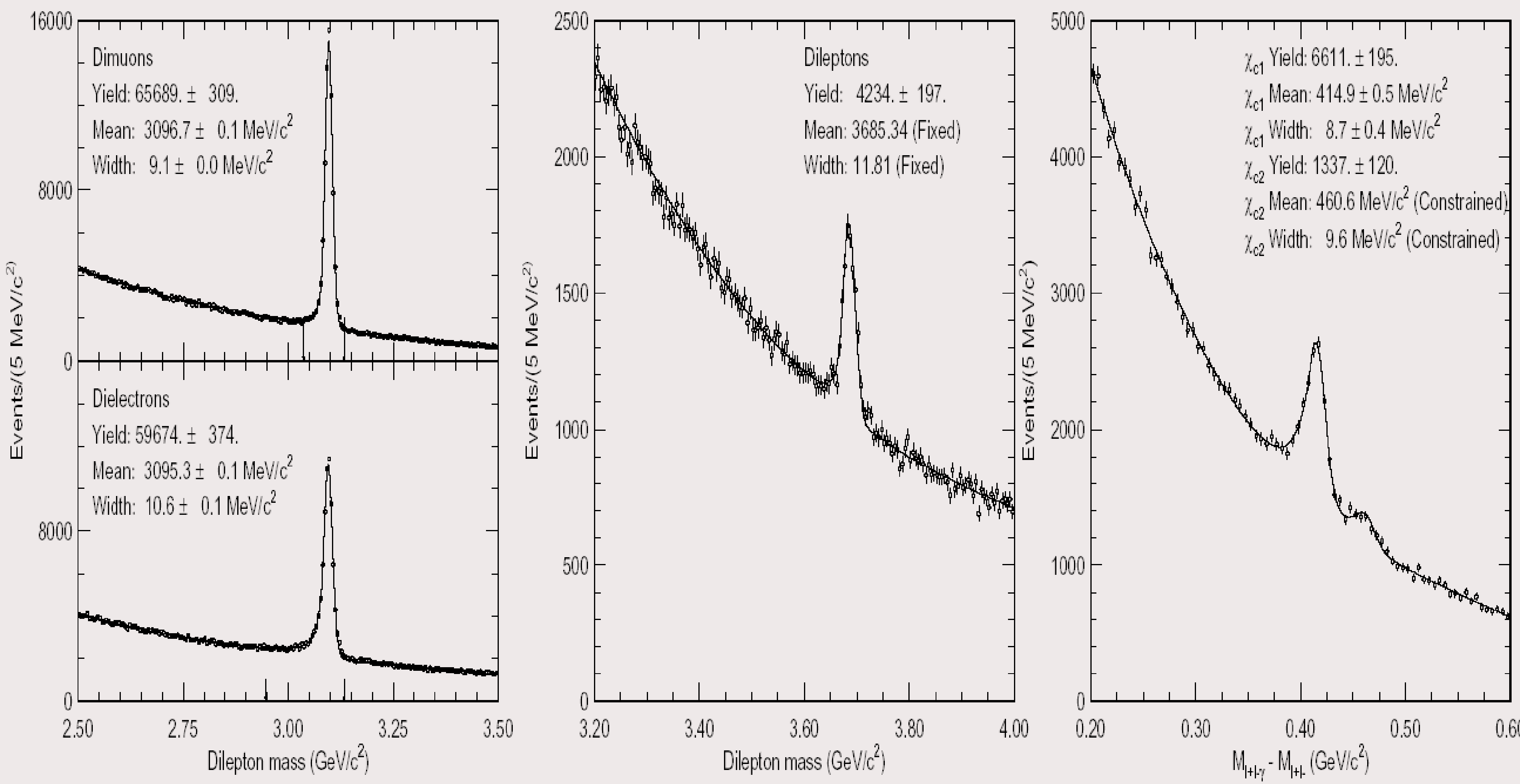
$$M = \sqrt{(\sum E_i)^2 - (\sum \vec{p}_i)^2}$$

The candidates for the X->xyz decay show up as a peak in the distribution on (mostly combinatorial) background.
The name of the game: have as little background under the peak as possible without loosing the events in the peak (=reduce background and have a small peak width).

A golden channel event



Reconstructing chamonium states



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

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

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

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

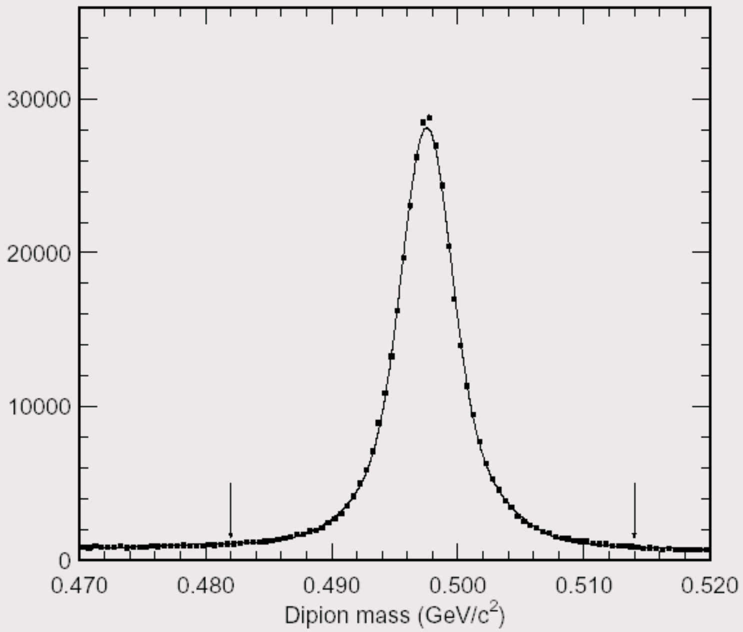
$\chi_{c1}, \chi_{c2} \to J/\psi\gamma$

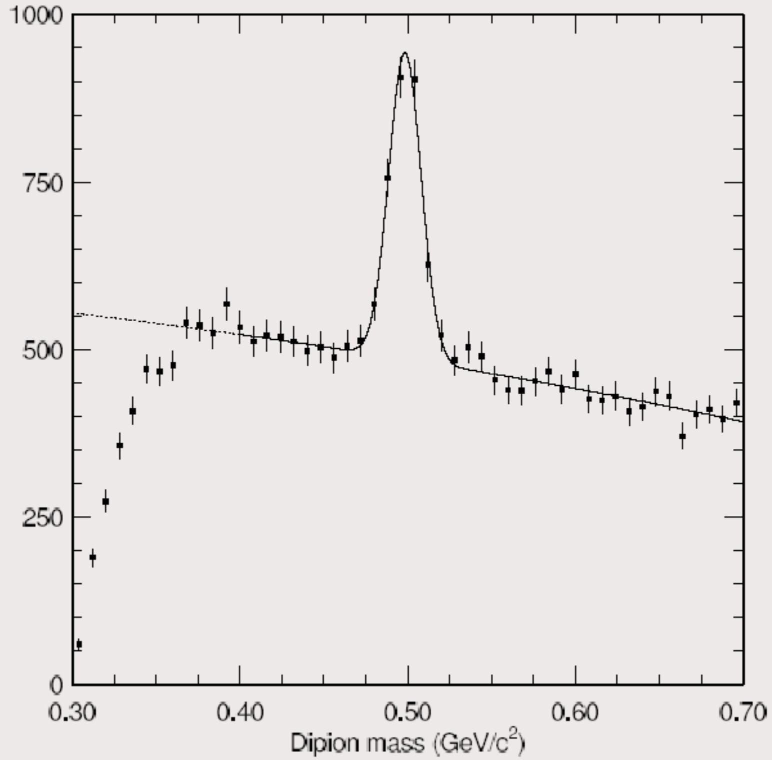
$\sigma_{\Delta M} = 7.0\mathrm{GeV}/c^2$

Reconstructing K^0_S

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

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

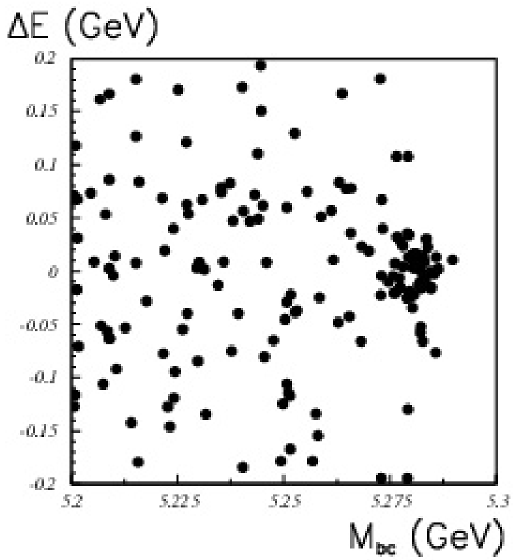


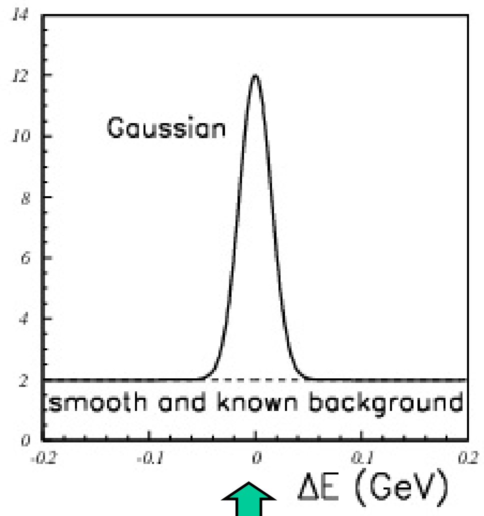


$K_S \to \pi^0\pi^0$

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

Reconstruction of rare B meson decays



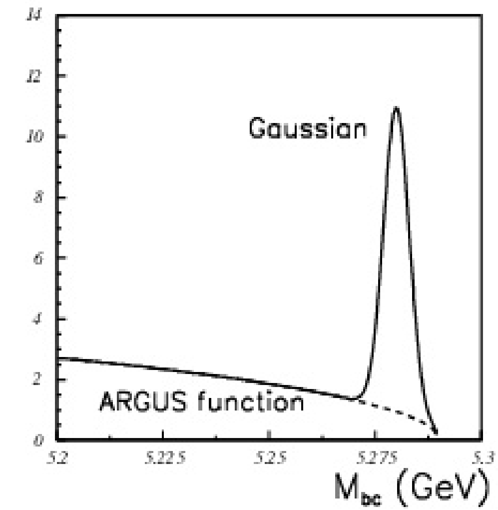


Reconstructing rare B meson decays at Y(4s): use two variables,

beam constrained mass M_{bc}

and

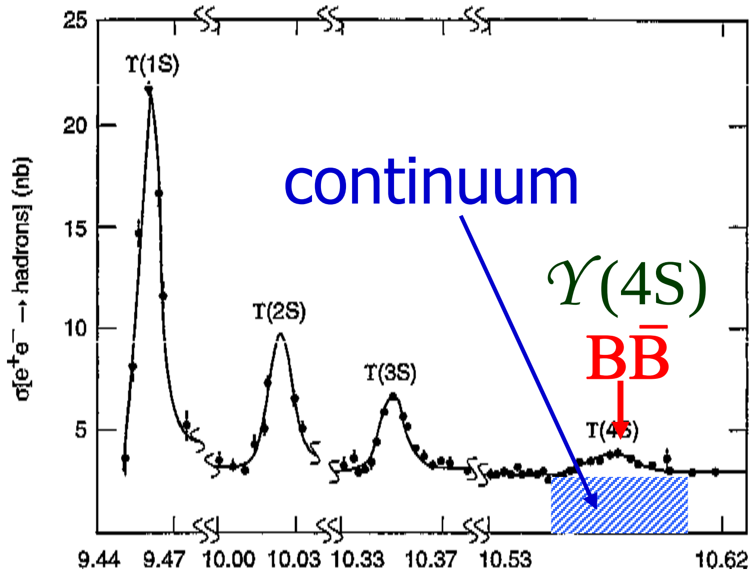
energy diference ΔE



$$\Delta E \equiv \sum E_i - E_{CM}/2$$

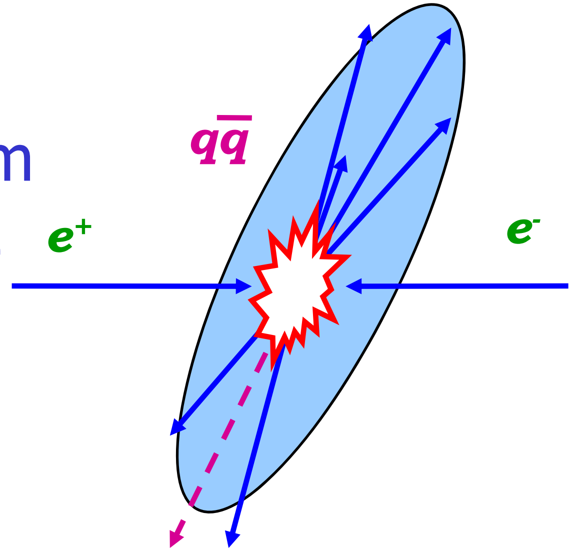
$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum \vec{p}_i)^2}$$

Continuum suppression



Continuum

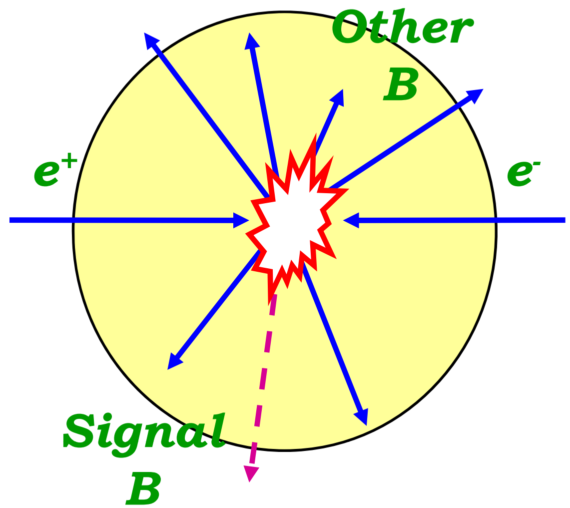
Jet-like



$e^+e^- \to qq$ "continuum" (~3x BB)

BB

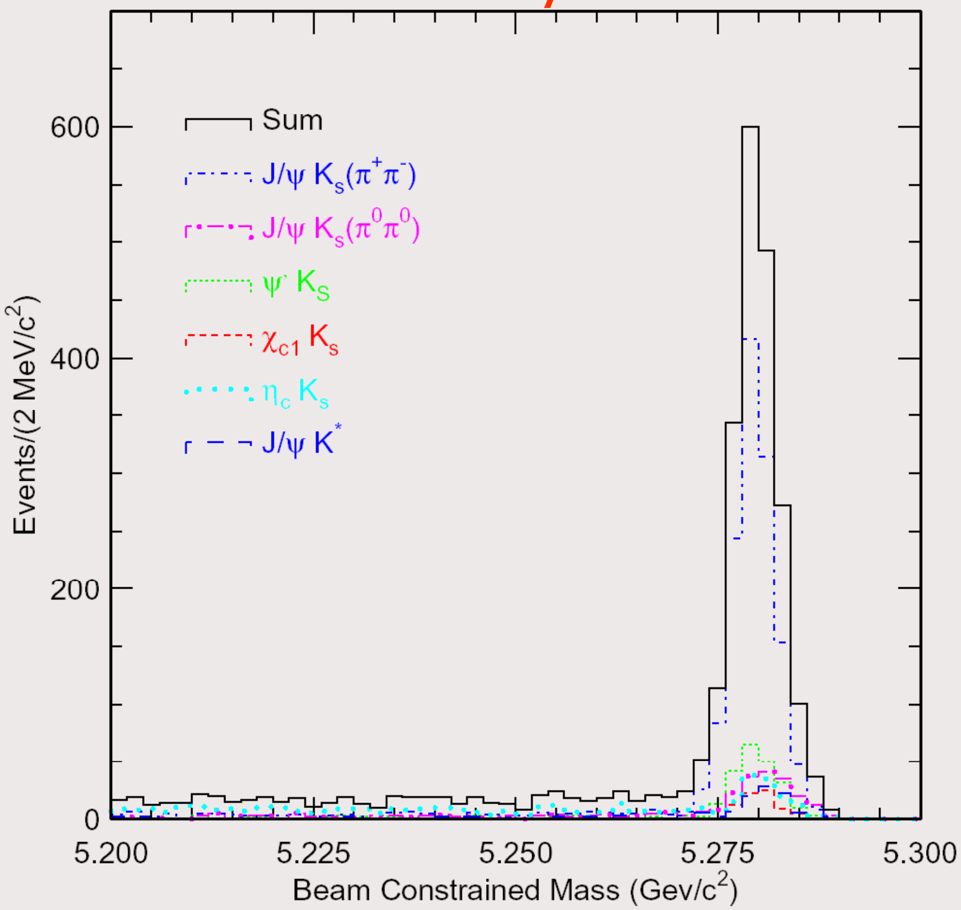
spherical



To suppress: use event shape variables

Reconstruction of b-> c anti-c s CP=-1 eigenstates

Reconstructed decay modes for 78/fb, 85M B B pairs, Belle 2002 result



$B^0 \to$	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
$\eta_c(\eta_c \to K K\pi^0)K_S$	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

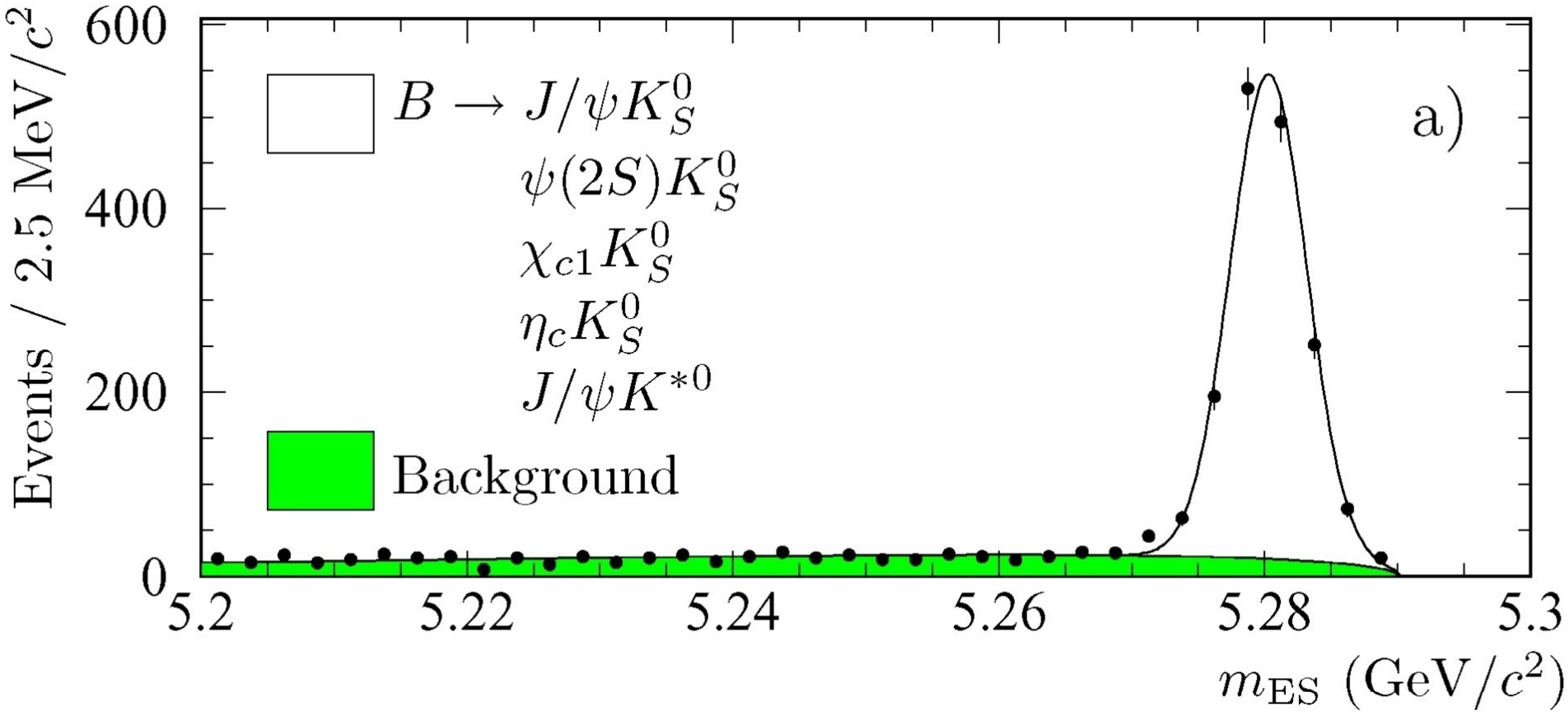
$$M_{bc} = \sqrt{E^2_{\text{beam}} - \vec{p}^{\,2}_{\text{Bcandidate}}}$$

2958 events are used in the fit

Reconstruction of b-> c anti-c s CP=-1 eigenstates

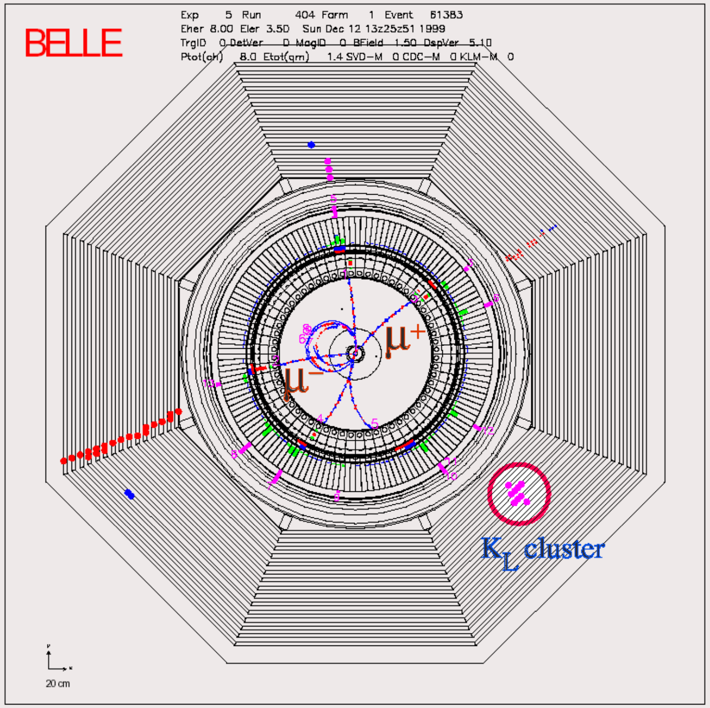
$J/\Psi(\Psi,\chi_{c1},\eta_c)\ K_s(K^{*0})$ sample (η_f=-1)
from 88(85)x10^6 $B\bar{B}$

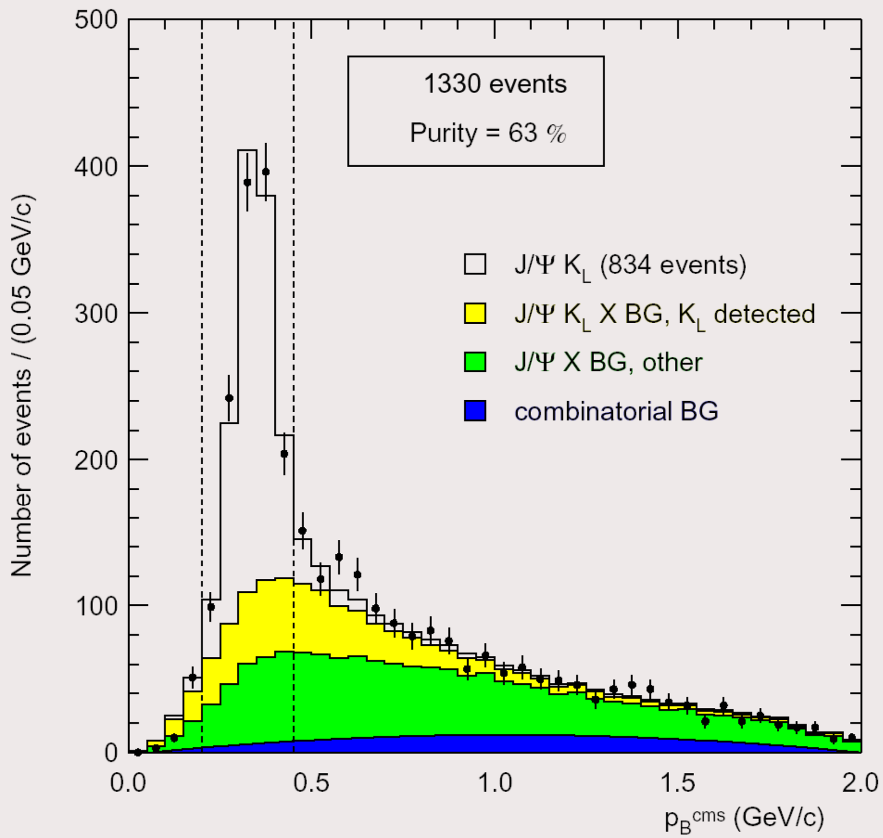
BaBar 2002 result



Reconstruction of b-> c anti-c s CP=+1 eigenstates

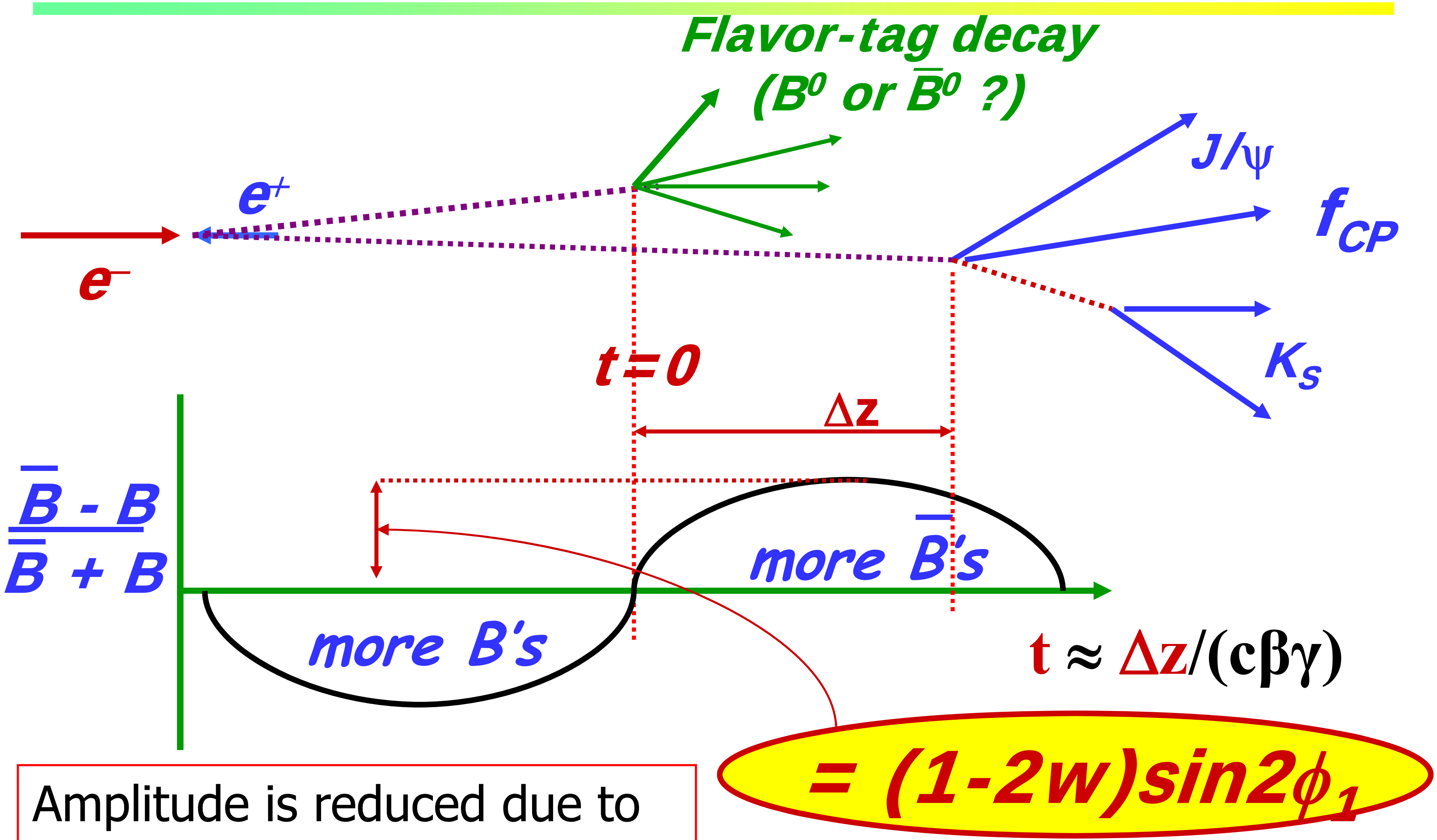
- detection of K_L in KLM and ECL
- K_L direction, no energy





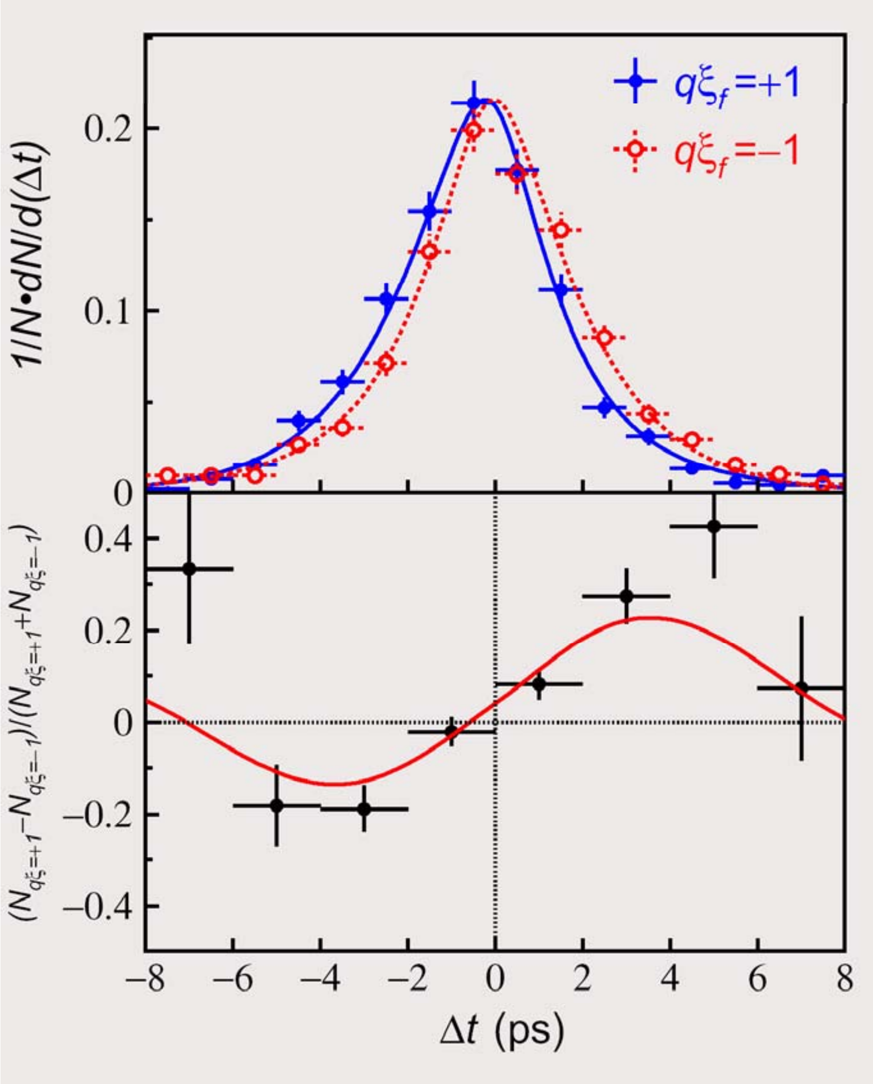
- $p^* \approx 0.35$ GeV/c for signal events
- background shape is determined from MC, and its size from the fit to the data

Principle of CPV Measurement



Amplitude is reduced due to imperfect tagging

Final result



CP is violated! Red points differ from blue.

Red points: anti-B^0 -> f_{CP} with CP=-1 (or B^0 -> f_{CP} with CP=+1)

Blue points: B^0 -> f_{CP} with CP=-1 (or anti-B^0 -> f_{CP} with CP=+1)

Belle, 2002 statistics
(78/fb, 85M B B pairs)

Fitting the asymmetry

Fitting function:

$$P_{sig}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left\{1 + q(1-2w_l)\,\mathrm{Im}\,\lambda \sin \Delta m t\right\} \otimes R(t)$$

Miss-tagging probability

Resolution function: from self-tagged events $B \to D^* l\nu, D\pi, \ldots$

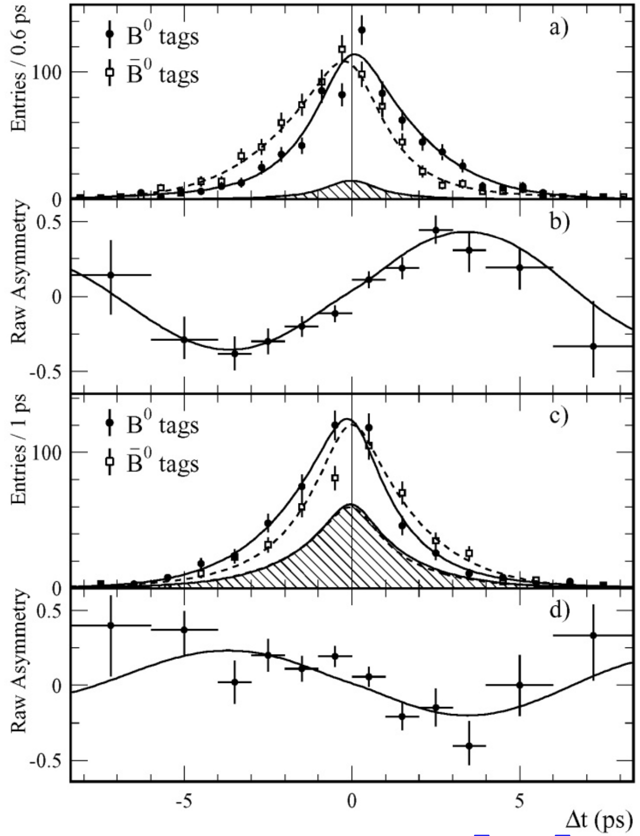
q=+1 or =-1 (B or anti-B on the tag side)

Fitting: unbinned maximum likelihood fit event-by-event

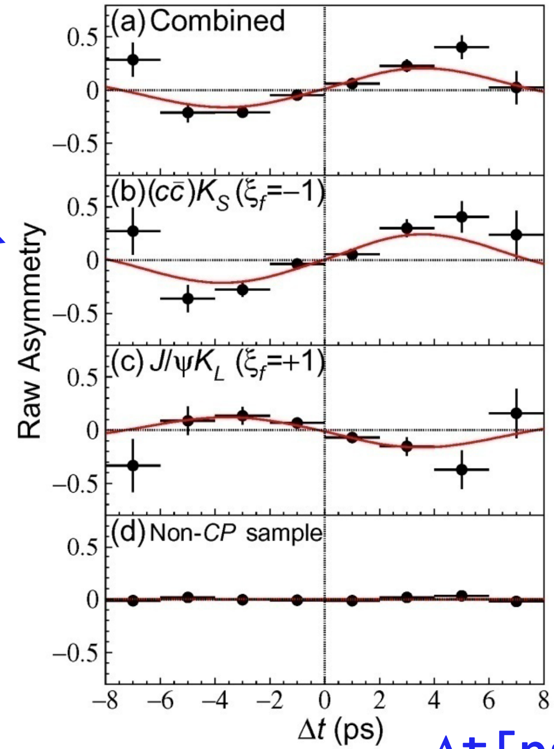
Fitted parameter: Im(λ)

BaBar vs Belle sin2ϕ_1

asymmetry



Δt[ps]



Δt[ps]

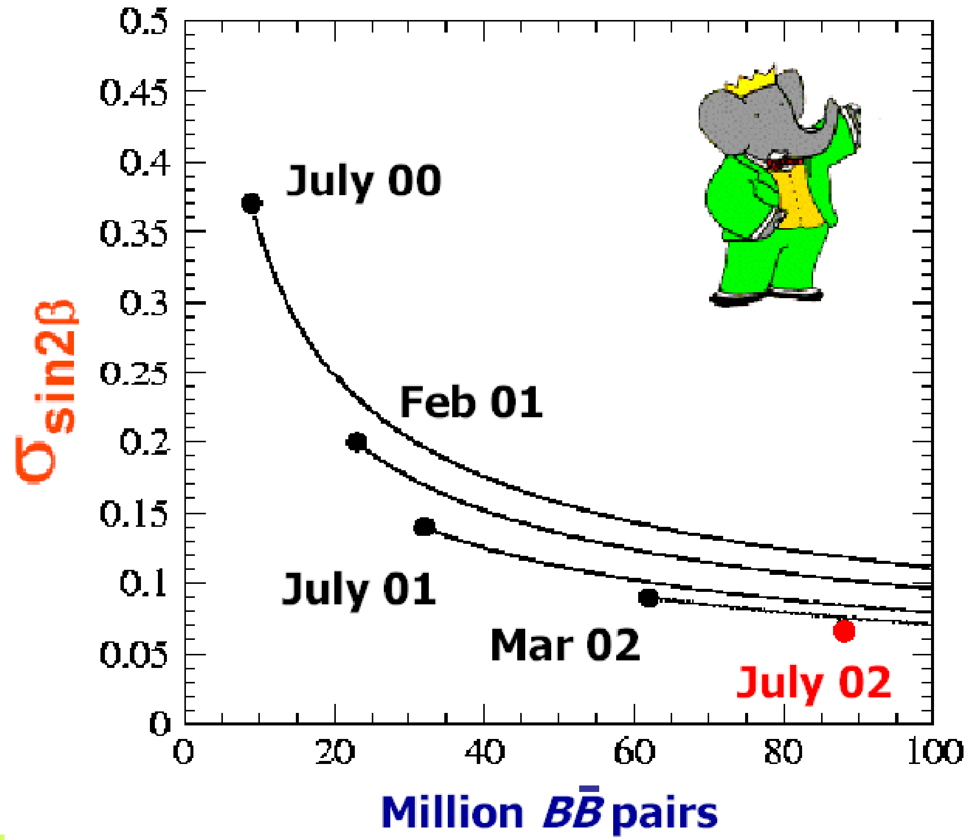
sin2ϕ_1=0.741±0.067±0.034 (BaBar)

sin2ϕ_1=0.719±0.074±0.035 (Belle)

More data....

Larger sample →
- smaller statistical error (1/√N)
- better understanding of the detector, calibration etc

→ error improves by better than with 1/√N



$b \to c$ anti-c s
CP=+1 and CP=-1 eigenstates

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

Asymmetry sign depends on the CP parity of the final state f_{CP}, η_{fcp}=+-1

$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}$$

$J/\psi\ K_S\ (\pi^+ \pi^-)$: CP=-1

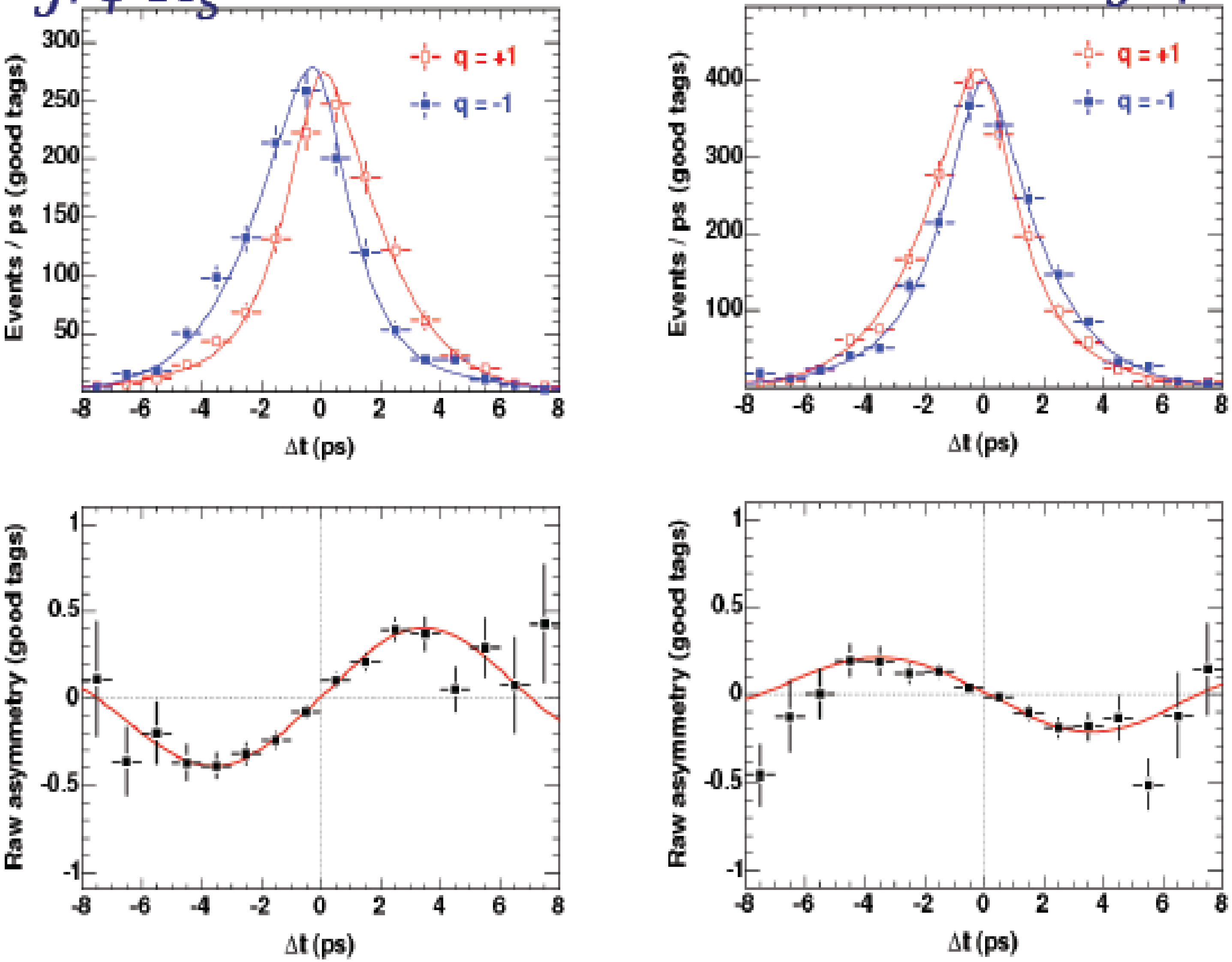
- J/ψ: P=-1, C=-1 (vector particle $J^{PC}=1^{--}$): CP=+1
- $K_S\ (\to \pi^+ \pi^-)$: CP=+1, orbital ang. momentum of pions=0 -> $P(\pi^+ \pi^-)=(\pi^- \pi^+)$, $C(\pi^- \pi^+) = (\pi^+ \pi^-)$
- orbital ang. momentum between J/ψ and K_S l=1, $P=(-1)^1=-1$

$J/\psi\ K_L(3\pi)$: CP=+1

Opposite parity to $J/\psi\ K_S\ (\pi^+ \pi^-)$, because $K_L(3\pi)$ has CP=-1

$Belle\ (386\times10^6\ B\bar{B})$

$J/\psi\ K_S$ $J/\psi\ K_L$

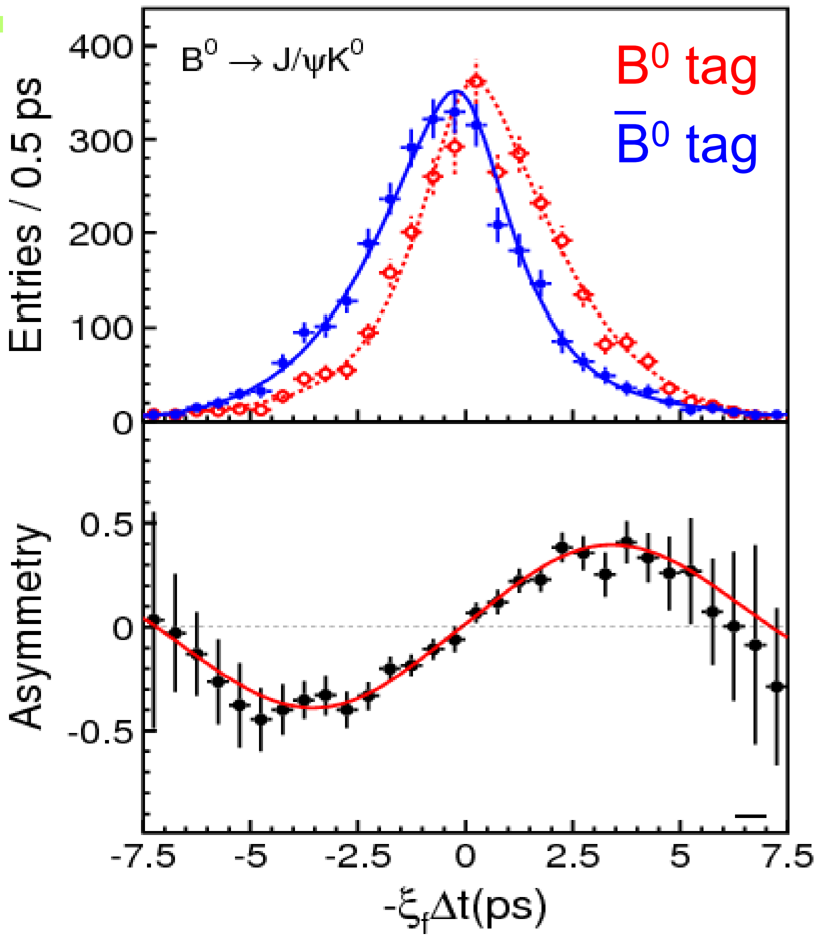


CP violation in the B system

CP violation in B system: from the discovery in $B^0 \rightarrow J/\Psi K_s$ decays (2001) to a precision measurement (2006)

$\sin 2\phi_1 = \sin 2\beta$ from $b \rightarrow c\bar{c}s$

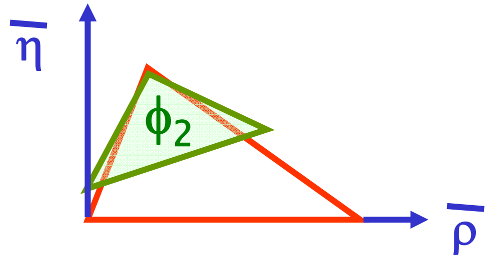
535 M $B\bar{B}$ pairs



$\sin 2\phi_1 = 0.642 \pm 0.031$ (stat) ± 0.017 (syst)

How to measure ϕ_2 (α)?

To measure $\sin 2\phi_2$, we measure the time dependent CP asymmetry in $B^0 \to \pi\pi$ decays



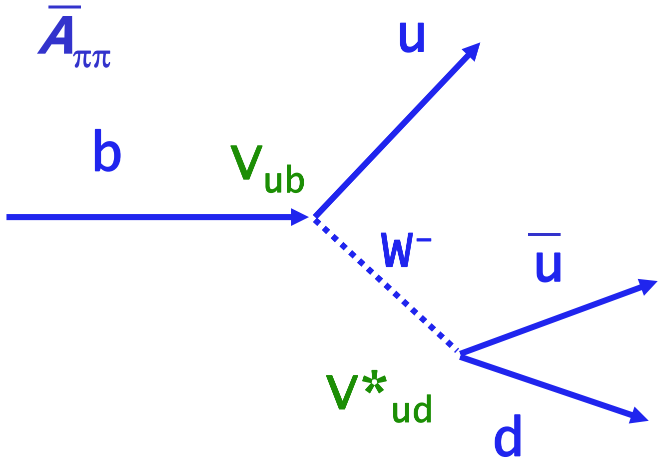
$$a_{f_{CP}} = \frac{P(\overline{B}^0 \to f_{CP}, t) - P(B^0 \to f_{CP}, t)}{P(\overline{B}^0 \to f_{CP}, t) + P(B^0 \to f_{CP}, t)} =$$

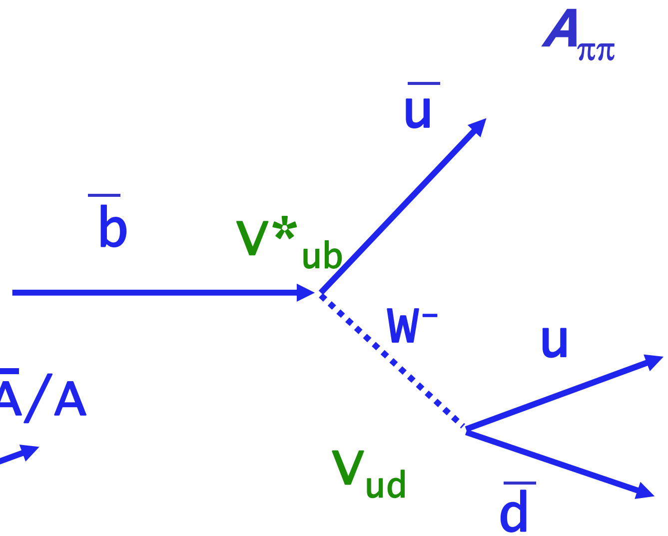
$$= \frac{(1 - |\lambda_{f_{CP}}|^2)\cos(\Delta m t) - 2\,\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t)}{1 + |\lambda_{f_{CP}}|^2}$$

$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \frac{\overline{A}_{\overline{f}_{CP}}}{A_{f_{CP}}}$$

In this case in general $\lambda \neq 1 \to$ much harder to extract ϕ_2 from the CP violation measurement

Decay asymmetry calculation for B->$\pi^+ \pi^-$ - tree diagram only





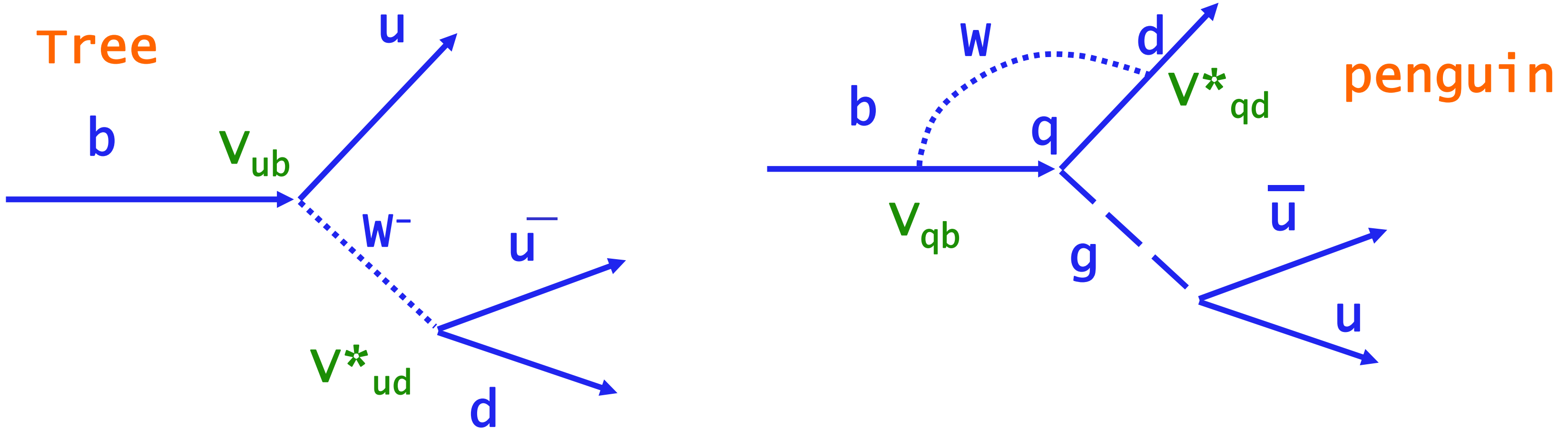
(q/p) $\bar{A}/A$

$$\lambda_{\pi\pi} = \eta_{\pi\pi} \left(\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \right) \left(\frac{V_{ud}^* V_{ub}}{V_{ud} V_{ub}^*} \right)$$

$$\mathrm{Im}(\lambda_{\pi\pi}) = \sin 2\phi_2 = \sin 2\alpha$$

Neglected possible penguin amplitudes ->

$\pi^+ \pi^-$ - tree vs penguin

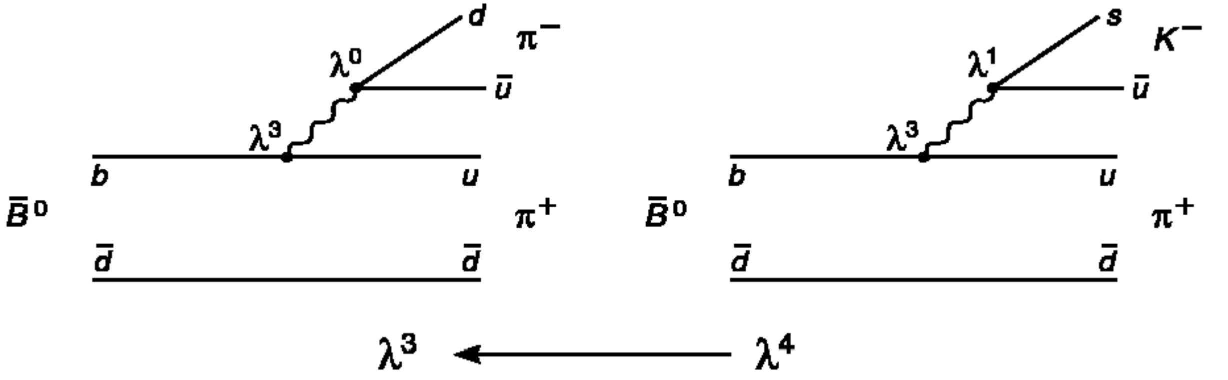


$V_{ub}V_{ud}^* = A\lambda^3(\rho - i\eta)$
$V_{tb}V_{td}^* = A\lambda^3(1-\rho + i\eta)$

How much does the penguin contribute?

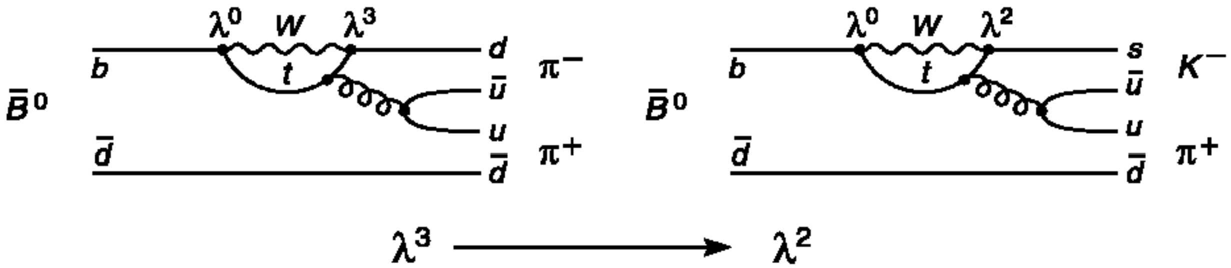
Compare $B \rightarrow K^+\pi^-$ and $B \rightarrow \pi^+\pi^-$ →

Diagrams for B→ $\pi\pi$, Kπ decays



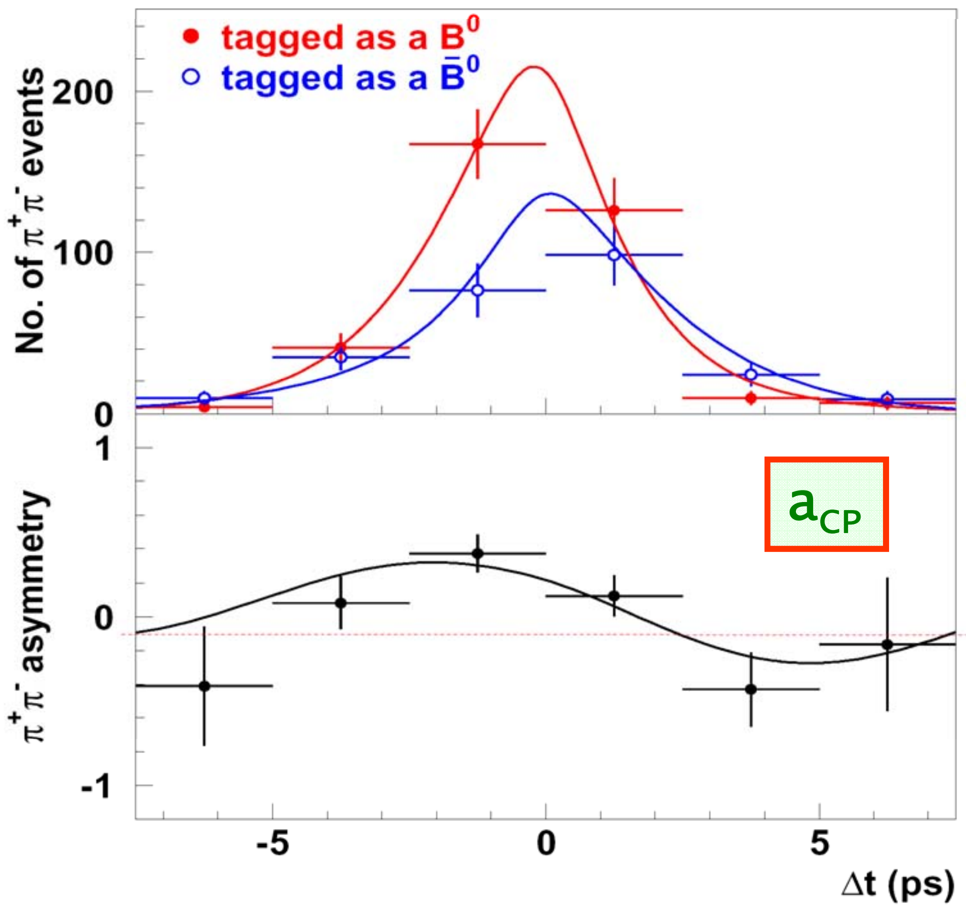
$\pi\pi$

Kπ



- Penguin amplitudes (without CKM factors) expected to be equal in both.
- BR($\pi\pi$) ~ 1/4 BR(Kπ)
- Kπ: penguin dominant → penguin in $\pi\pi$ must be important

B→$\pi^+ \pi^-$: results of the fit, plotted with background subtracted



$$a_{f_{CP}} = \frac{P(\overline{B}^0 \to f_{CP}, t) - P(B^0 \to f_{CP}, t)}{P(\overline{B}^0 \to f_{CP}, t) + P(B^0 \to f_{CP}, t)} =$$

$$= S_{f_{CP}} \sin(\Delta m t) - A_{f_{CP}} \cos(\Delta m t)$$

$\mathcal{S}_{\pi\pi}$ = -0.67±0.16±0.06

$\mathcal{A}_{\pi\pi}$ = 0.56±0.12±0.06

→ direct CP violation!

Evident on this plot:
Number of anti-B events
< Number of B events

CP asymmetry in time integrated rates

$$a_f = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B} \to \overline{f})} = \frac{1 - |\overline{A}/A|^2}{1 + |\overline{A}/A|^2}$$

Need $|\overline{A}/A| \neq 1$: how do we get there?

In general, A is a sum of amplitudes with strong phases δ_i and weak phases ϕ_i. The amplitudes for anti-particles have the same strong phases and opposite weak phases ->

$$A_f = \sum_i A_i e^{i(\delta_i + \varphi_i)}$$

$$\overline{A}_{\overline{f}} = \sum_i A_i e^{i(\delta_i - \varphi_i)}$$

$$\left|A_f\right|^2 - \left|\overline{A}_{\overline{f}}\right|^2 = \sum_{i,j} A_i A_j \sin(\varphi_i - \varphi_j) \sin(\delta_i - \delta_j)$$

→ Need at least two interfering amplitudes with different weak and strong phases.

B->π⁺ π⁻: interpretation

Interpretation:

tree level

tree + 

$$\lambda_{\pi\pi} = e^{2i\phi_2} \quad \rightarrow \quad \lambda_{\pi\pi} = e^{2i\phi_2} \frac{1+|P/T|\, e^{i\delta + i\phi_3}}{1+|P/T|\, e^{i\delta - i\phi_3}} \equiv |\lambda_{\pi\pi}|\, e^{2i\phi_{2eff}}$$

strong phase diff. P-T

weak phase (changes sign)

$$A_{\pi\pi} = 0 \quad \rightarrow \quad A_{\pi\pi} \propto \sin\delta$$

$$S_{\pi\pi} = \sin(2\phi_2) \quad \rightarrow \quad S_{\pi\pi} = \sqrt{1 - A^2_{\pi\pi}}\, \sin(2\phi_{2eff})$$

ϕ_{2eff} depends on δ, ϕ_3, ϕ_2 and |P/T|

$\pi = \phi_1 + \phi_2 + \phi_3 \rightarrow \phi_{2eff}$ depends on δ, ϕ_1, ϕ_2 and |P/T|

ϕ_1: well measured

Extraction of ϕ_2

Use measured BRs and asymmetries in all three $B \to \pi\pi$ decays
$\longrightarrow$ extract ϕ_2

Similar analysis as for $B \to \pi\pi$ also for $B \to \rho\rho$

(ϕ_2^{eff} closer to ϕ_2)

... and for $B \to \rho\pi$

BaBar/Belle

S_{+-} $Br(B^0 \to \pi^0\pi^0)$

A_{+-} $Br(B^0 \to \pi^+\pi^-)$

$\mathcal{A}_{CP}$ $Br(B^+ \to \pi^+\pi^0)$

BaBar

Similar from $B \to \rho\rho$

BaBar/Belle

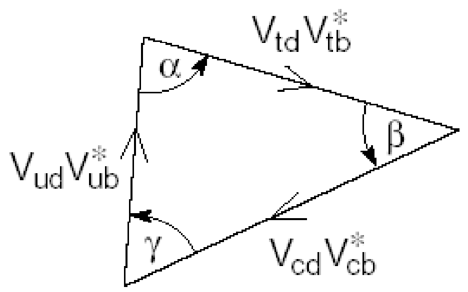
Similar from $B \to \rho\pi$

$\phi_2 = 106^o \pm {}^{8^o}_{11^o}$

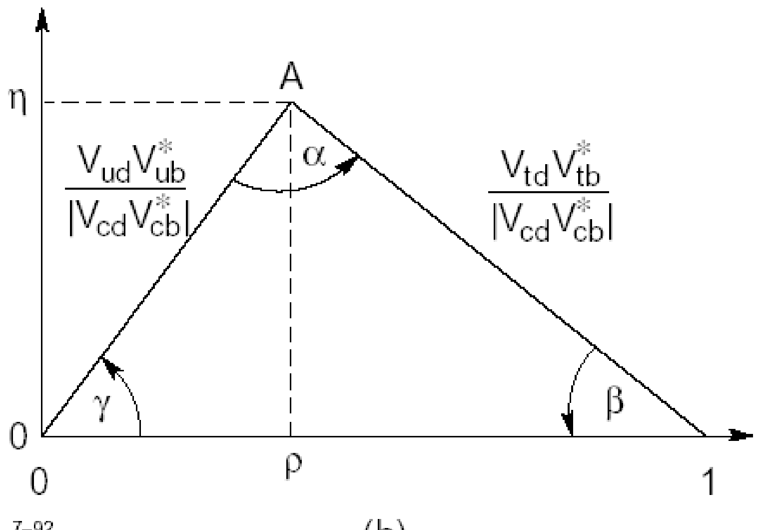
How to measure ϕ_3?

No easy (=tree dominated) channel to measure ϕ_3 through CP violation.

Any other idea? Yes.



(a)



(b)

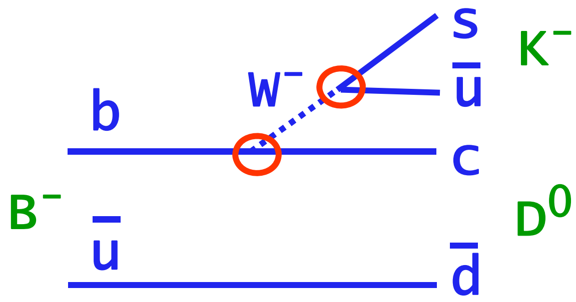
$$\gamma \equiv \phi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

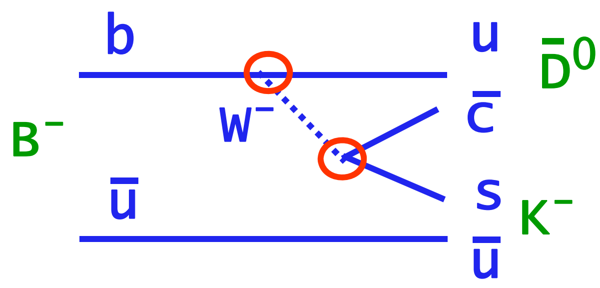
ϕ_3 from interference of a direct and colour suppressed decays

Basic idea: use $B^- \to K^- D^0$ and $B^- \to K^- \bar{D}^0$ with $D^0, \bar{D}^0 \to f$

interference ↔ ϕ_3

f: any final state, common to decays of both D^0 and $\bar{D}^0$





$T \sim V_{cb}^* V_{us} \sim A\lambda^3$ $T_c \sim V_{ub}^* V_{cs} \sim A\lambda^3 (\rho + i\eta)$

$(\rho + i\eta) \sim e^{i\phi_3}$

ϕ_3 from interference of a direct and colour suppressed decays

Gronau,London,Wyler, 1991: $B^- \to K^- D^0_{CP}$
Atwood,Dunietz,Soni, 2001: $B^- \to K^- D^{0(*)}[K^+\pi^-]$
Belle;Giri,Zupan et al., 2003: $B^- \to K^- D^{0(*)}[K_s\pi^+\pi^-]$
Dalitz plot

Density of the Dalitz plot depends on ϕ_3

Matrix element:

$$M_+ = f(m_+^2, m_-^2) + re^{i\phi_3 + i\delta} f(m_-^2, m_+^2),$$

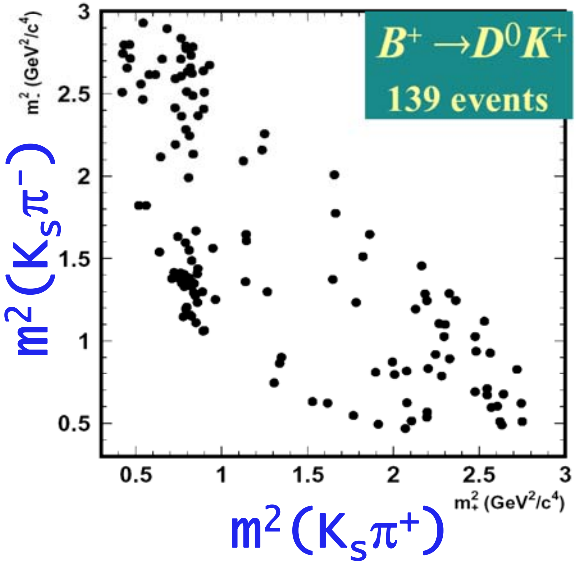
Sensitivity depends on

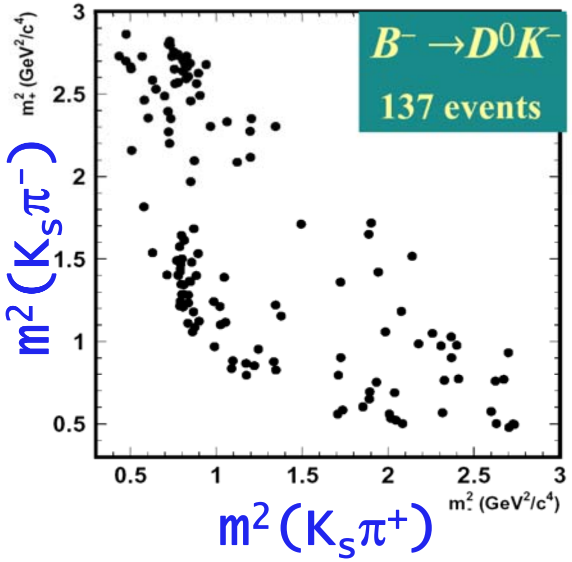
$$r = \sqrt{\frac{Br(B^- \to \overline{D}^{(*)0} K^-)}{Br(B^- \to D^{(*)0} K^-)}} \approx 0.1 - 0.3$$

or any other common 3-body decay

ϕ_3 from interference of a direct and colour suppressed decay

$B^+ \to D^0 K^+$ $\qquad\qquad$ $B^- \to D^0 K^-$





⇨ visible asymmetry

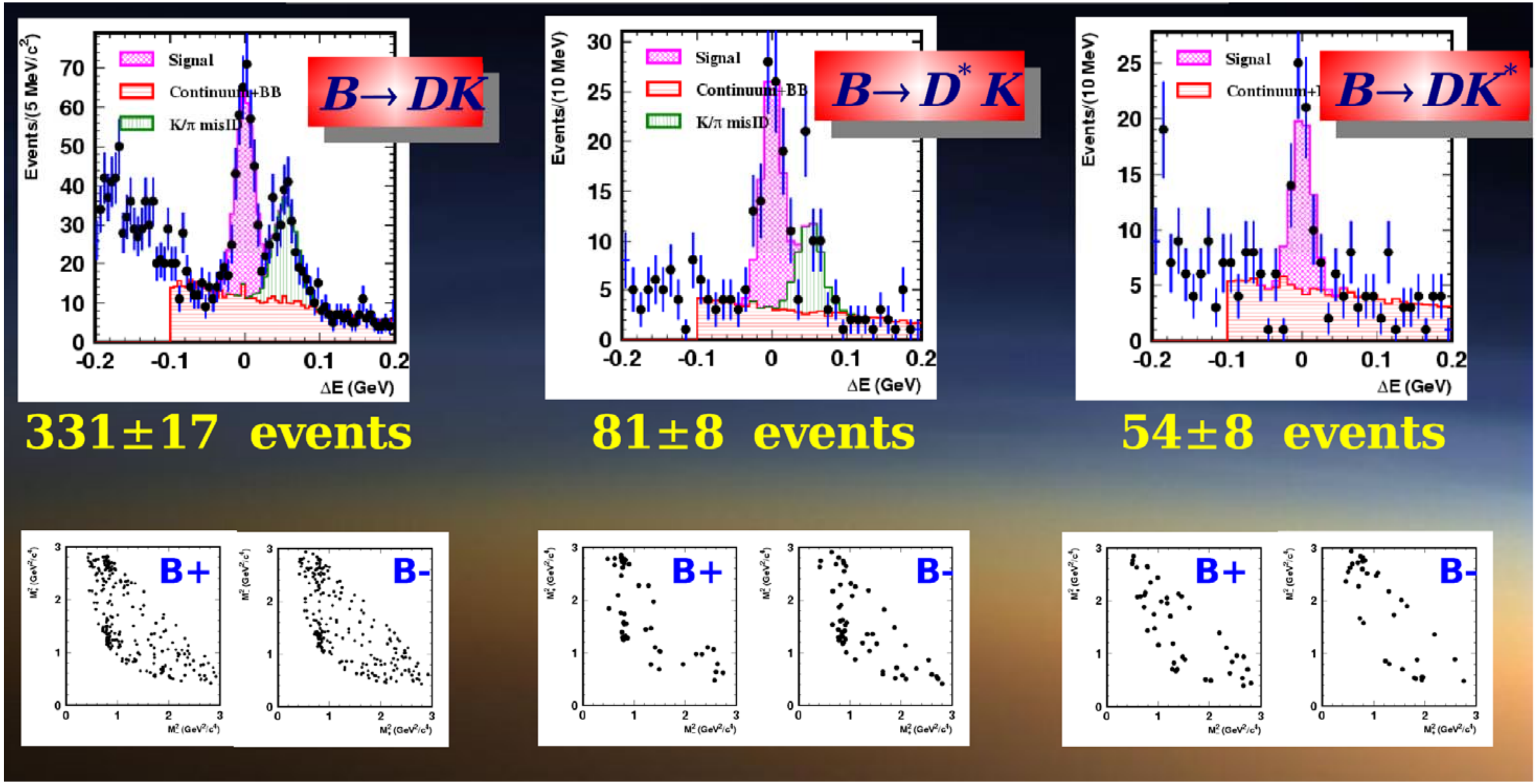
Fit with ϕ_3, δ, r_B free

$\phi_3 = (68 \pm ^{14}_{15} \pm 13 \pm 11)^o$

$22^o < \phi_3 < 113^o$ @ 95% C.L.

$r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$

Update 2006

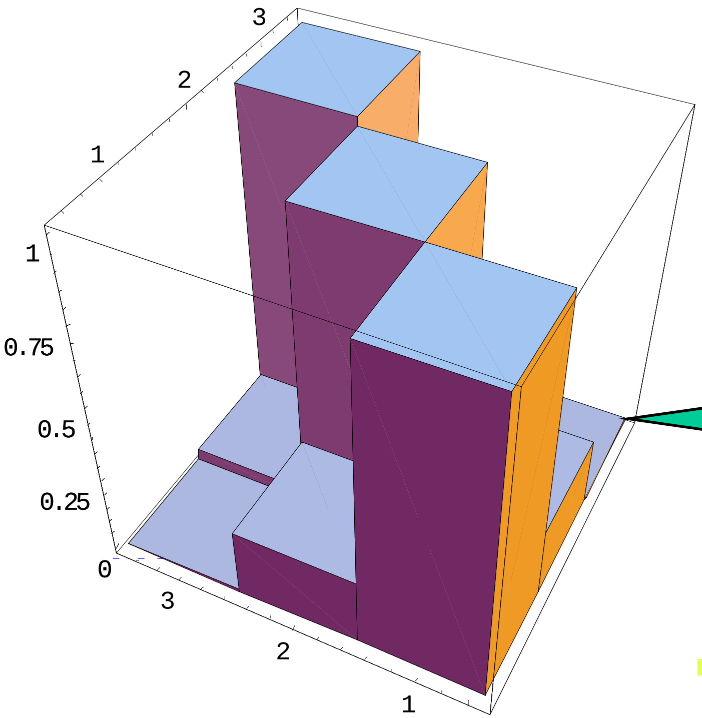


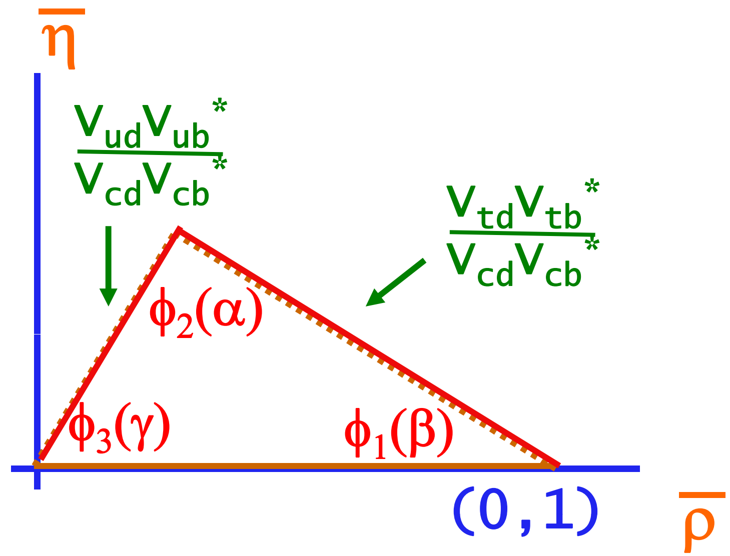
$\phi_3 = (53 \pm {}^{15}_{18}\ (\text{stat}) \pm 3\ (\text{syst}) \pm 9\ (\text{model}))^{o}$

Unitary triangle: one of the sides is determined by V_{ub}

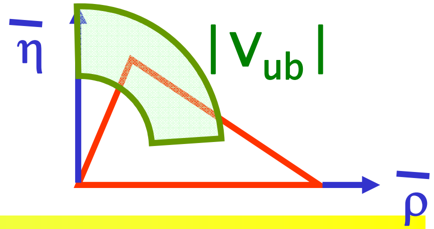
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

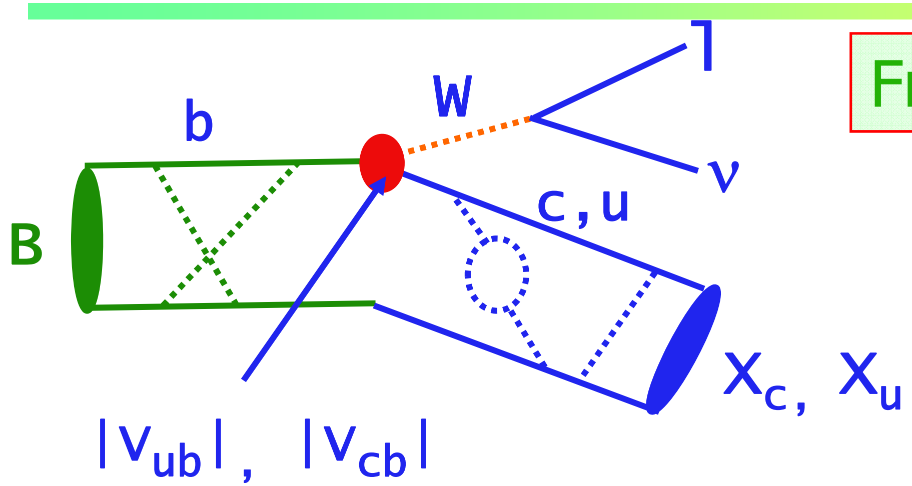
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$





$|V_{ub}|$ measurements





From semileptonic B decays

$b \to c l \nu$ background typically an order of magnitude larger.

Traditional inclusive method: fight the background from $b \to c l \nu$ decays by using only events with electron momentum above the $b \to c l \nu$ kinematic limit. Problem: extrapolation to the full phase space→ large theoretical uncertainty.

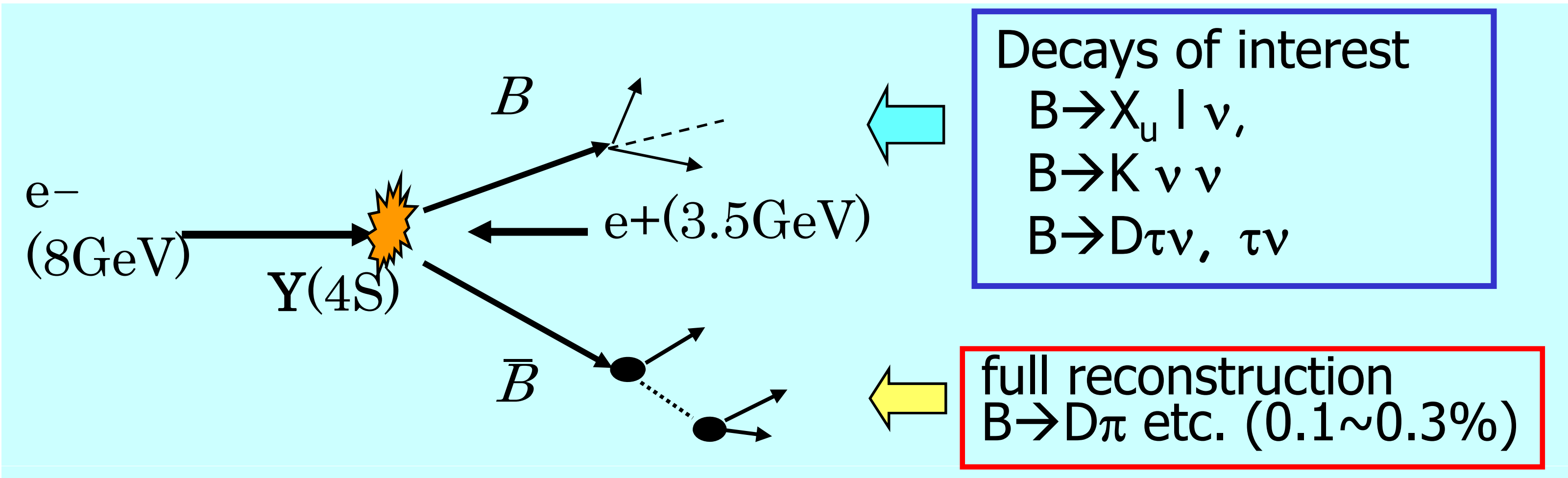
New method: fully reconstruct one of the B mesons, check the properties of the other (semileptonic decay, low mass of the hadronic system)

- Very good signal to noise
- Low yield (full reconstruction efficiency is 0.3-0.4%)

Full Reconstruction Method

Fully reconstruct one of the B's to

- Tag B flavor/charge
- Determine B momentum
- Exclude decay products of one B from further analysis



→ Offline B meson beam!

Powerful tool for B decays with neutrinos

Fully reconstructed sample

Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{reco} \approx 3\cdot10^{-3}$

Exclusive method: 180 decay channels

Reconstructed channels:

$B^0 \rightarrow D^{(*)-}\pi^+ \,/\, D^{(*)-}\rho^+ \,/\, D^{(*)-}a_1^+ \,/\, D^{(*)-} D_s^{(*)+}$

$B^+ \rightarrow D^{(*)0}\pi^+ \,/\, D^{(*)0}\rho^+ \,/\, D^{(*)0}a_1^+ \,/\, D^{(*)0} D_s^{(*)+}$

$D^{*0} \rightarrow D^0\pi^0$

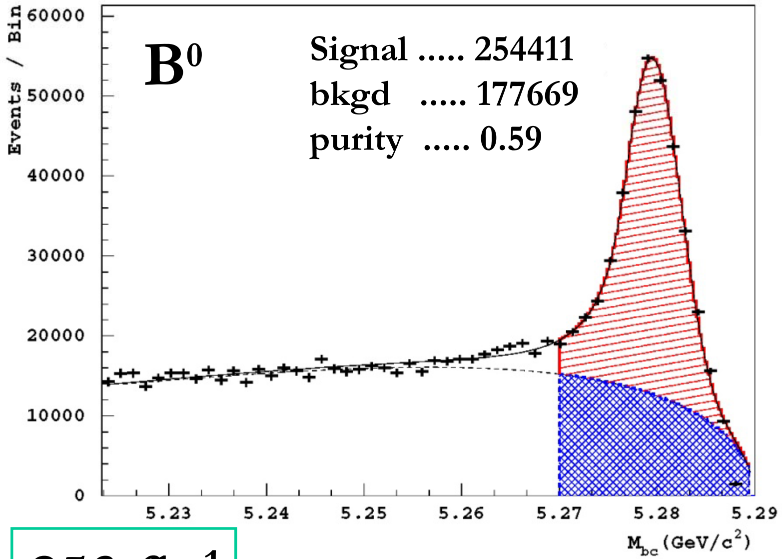
$D^* \rightarrow D^0\pi \,/\, D\pi^0$

$D_s^* \rightarrow D_s\gamma$

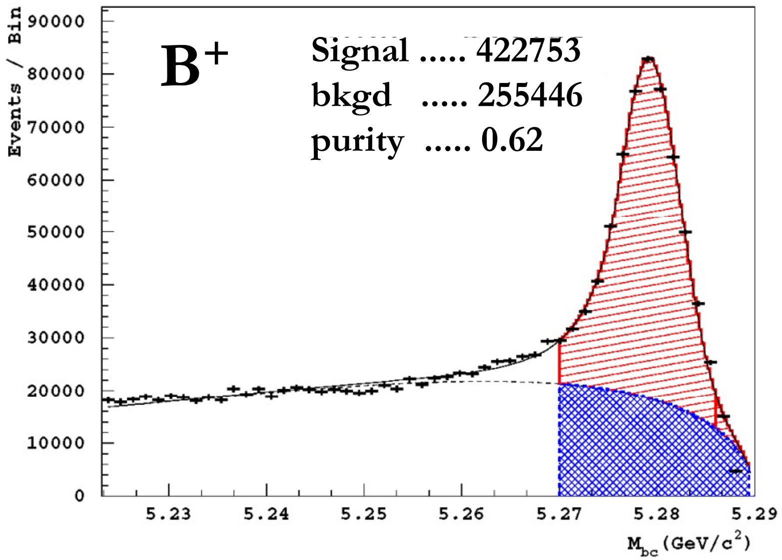
$D^0 \rightarrow K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

$D \rightarrow K\pi\pi / K\pi\pi\pi^0 / K_s\pi / K_s\pi\pi^0 / K_s\pi\pi\pi / KK\pi$

$D_s \rightarrow K_sK\pi / KK\pi$



253 fb^{-1}



M_x analysis

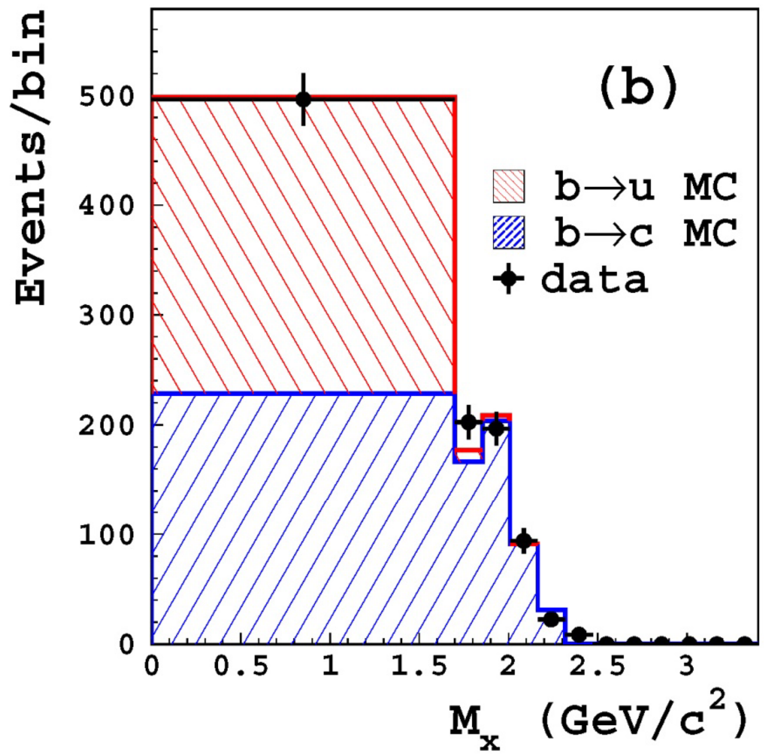
Use the mass of the hadronic system M_x as the discriminating variable against $b \to c l \nu$

M_x = mass of all hadrons from the B decay.

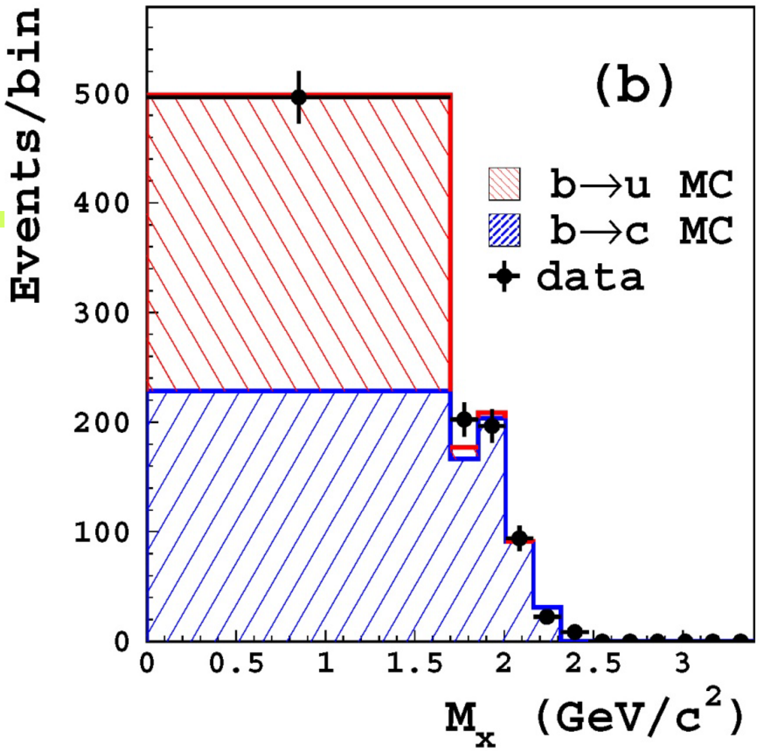
Expect:

• M_x for $b \to c l \nu$ to be above 1.8 GeV ($b \to c l \nu$ results in a D meson with >1.8 GeV)

• M_x for $b \to u l \nu$ to mainly below 1.8 GeV ($B \to \pi l \nu$, $\rho l \nu$, $\omega l \nu$ ...)



M_x analysis



M_x<1.7 GeV/c^2 / q^2>8 GeV^2/c^2

Total error on $|V_{ub}|$ 12%

253 fb^{-1}

$$|V_{ub}| = (4.93 \pm 0.25 \pm 0.22 \pm 0.15 \pm 0.13 \pm 0.46\ {}^{+0.20}_{-0.22}) \times 10^{-3}$$

stat syst b→u b→c SF theo
model dep.

M_x<1.7 GeV/c^2 / no q^2 cut : total error on $|V_{ub}|$ 11%

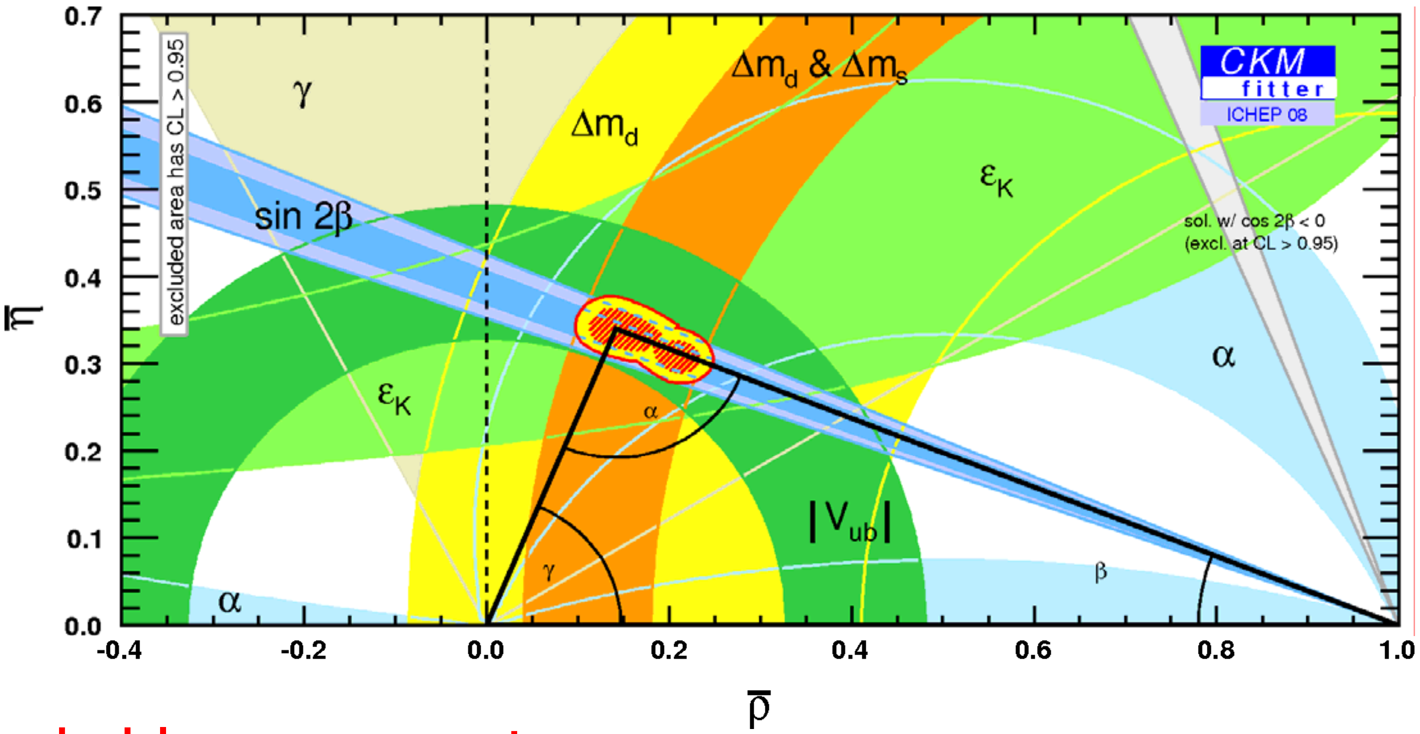
253 fb^{-1}

$$|V_{ub}| = (4.35 \pm 0.20 \pm 0.15 \pm 0.13 \pm 0.05 \pm 0.40\ {}^{+0.13}_{-0.14}) \times 10^{-3}$$

stat syst b→u b→c SF theo
model dep.

All measurements combined...

Constraints from measurements of angles and sides of the unitarity triangle →

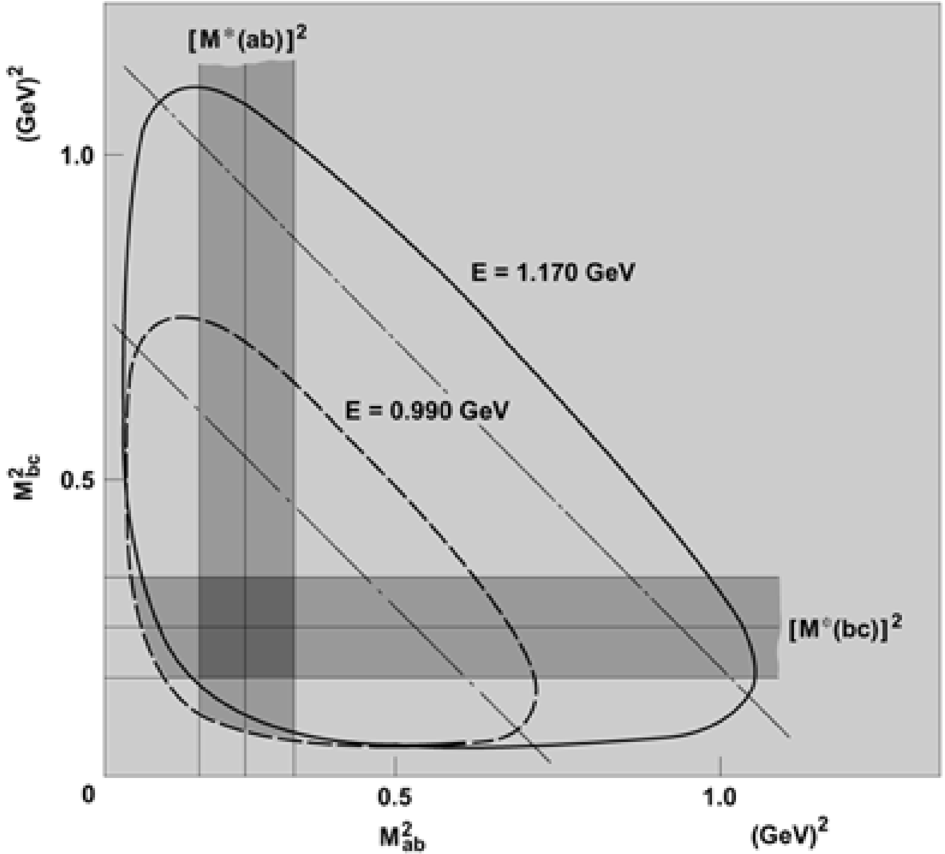


→ Remarkable agreement

Back-up slides

What is a Dalitz plot?

Example: three body decay X->abc. M_{ij} denotes the invariant mass of the two-particle system (*ij*) in a three body decay. Kinematic boundaries: drawn for equal masses $m_a = m_b = m_c = 0.14$ Ge and for two values of total energy *E* of the three-pion system. Resonance bands: drawn for states (*ab*) and (*bc*) corresponding to a (fictitious) resonanc with M=0.5 GeV and Γ=0.2 GeV; dot-dash lines show the locations a (*ca*) resonance band would have for this mass of 0.5 GeV, for the two values of the total energy *E*.



The pattern becomes much more complicated, if the resonances interfere.

Richard H. Dalitz, "Dalitz plot", in AccessScience@McGraw-Hill, http://www.accessscience.com.

ϕ_3 from interference of a direct and colour suppressed decay

Use D^0 decays from $D^{*-} \to D^0\pi^-$, $D^0 \to K_S\pi^+\pi^-$ decay to model Dalitz plot density in two variables:
$m^2(K_S\pi^+)=m_+^2$ and
$m^2(K_S\pi^-)=m_-^2$

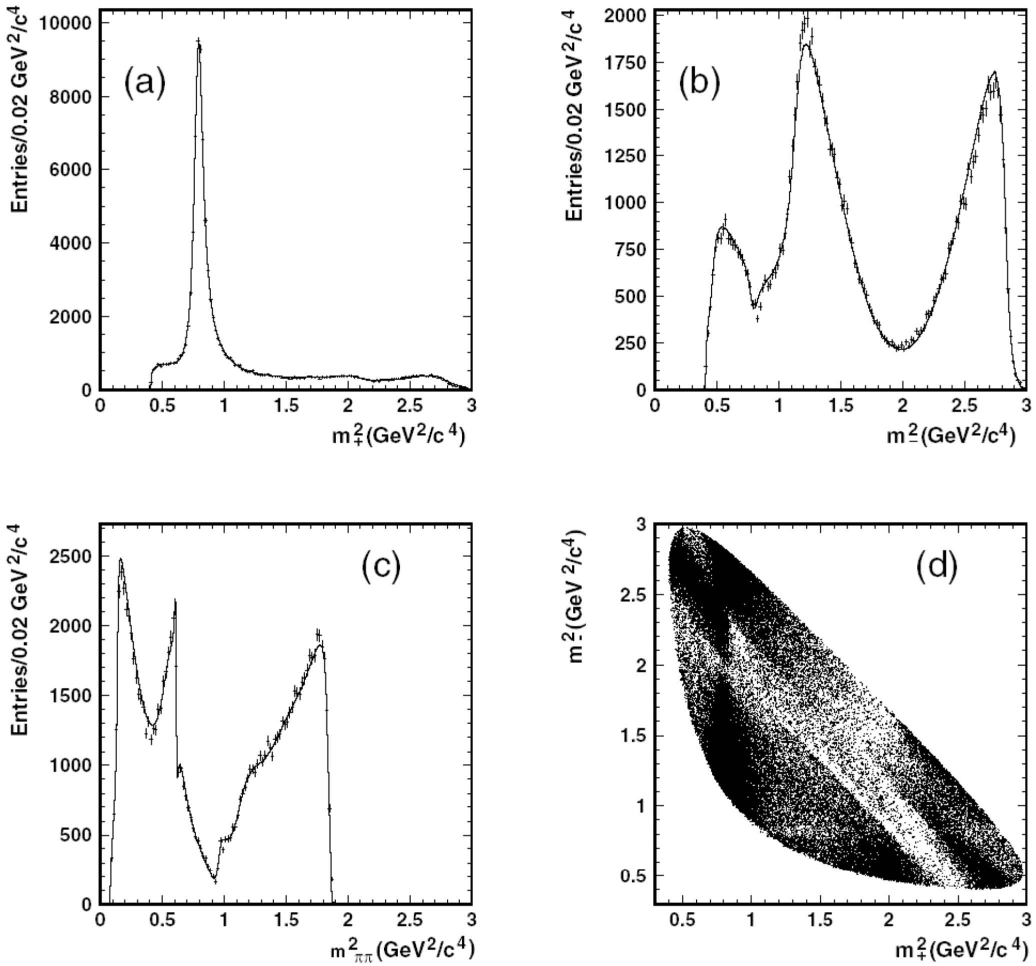
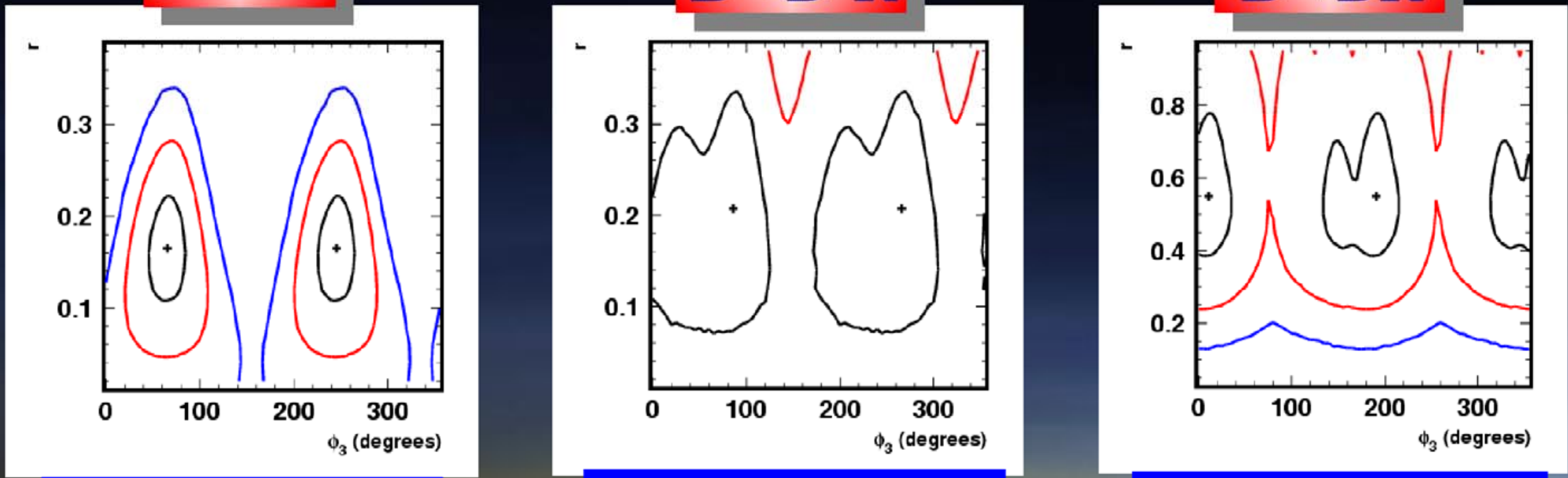


FIG. 5. (a) m_+^2, (b) m_-^2, (c) $m_{\pi\pi}^2$ distributions and (d) Dalitz plot for the $\bar{D}^0 \to K_S\pi^+\pi^-$ decay from the $D^{*\pm} \to D\pi_s^\pm$ process. The points with error bars show the data; the smooth curve is the fit result.

Update 2006

$B \to DK$ | $B \to D^* K$ | $B \to DK^*$



$\phi_3 = 66^{+19}_{-20} (degree)$ | $\phi_3 = 86^{+37}_{-93} (degree)$ | $\phi_3 = 11^{+23}_{-57} (degree)$

Combining 3 modes

$$\phi_3 = 53^{0}{}^{+15}_{-18} (stat.) \pm 3^0 (syst.) \pm 9^0 (model)$$

$|V_{ub}|$ Results

Lepton endpoint (p* > 1.9 GeV/c)

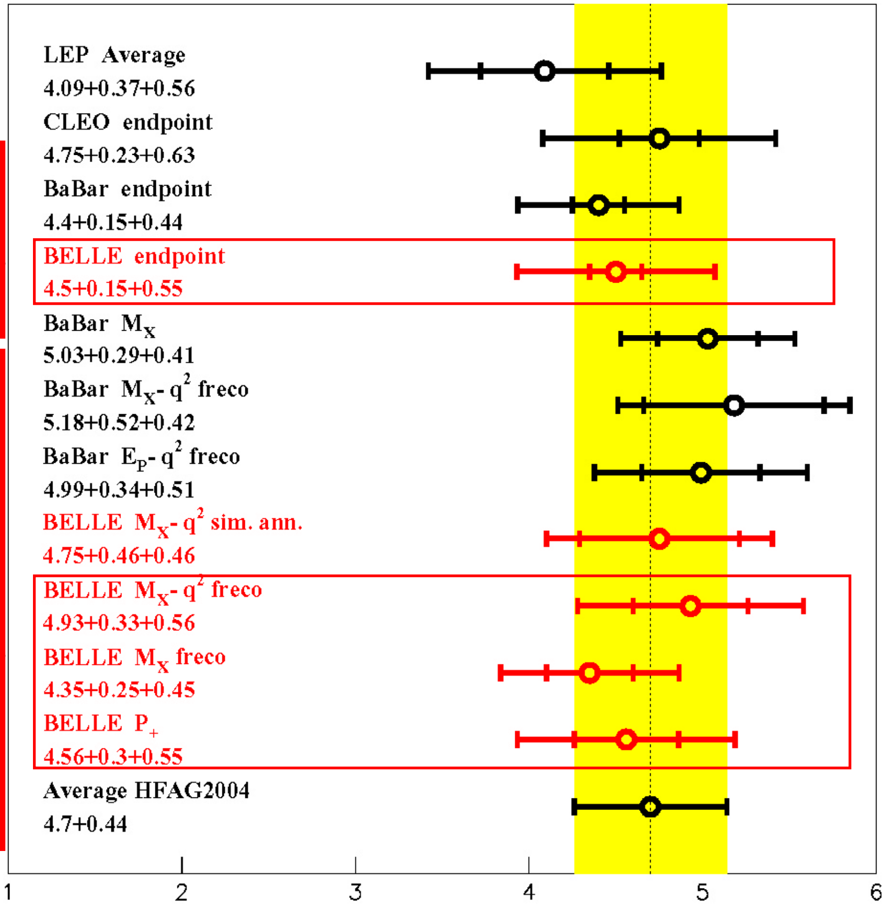
$|V_{ub}| = (4.50 \pm 0.15 \pm 0.55) \times 10^{-3}$ 13%

Full reconstruction tagging

M_x/q^2: $|V_{ub}| = (4.93 \pm 0.33 \pm 0.56) \times 10^{-3}$ 13%

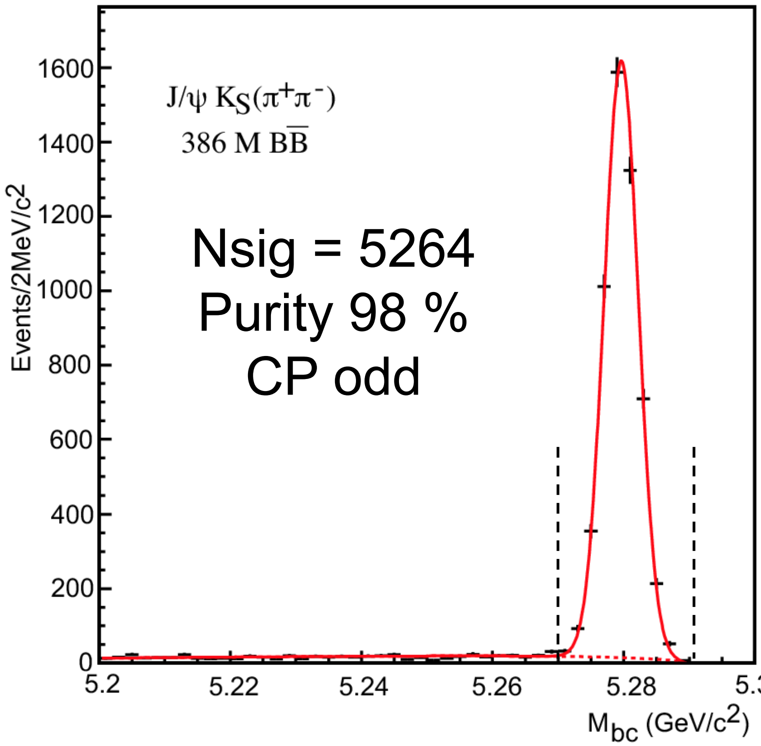
M_x: $|V_{ub}| = (4.35 \pm 0.25 \pm 0.45) \times 10^{-3}$ 12%

P_+: $|V_{ub}| = (4.56 \pm 0.30 \pm 0.55) \times 10^{-3}$ 14%



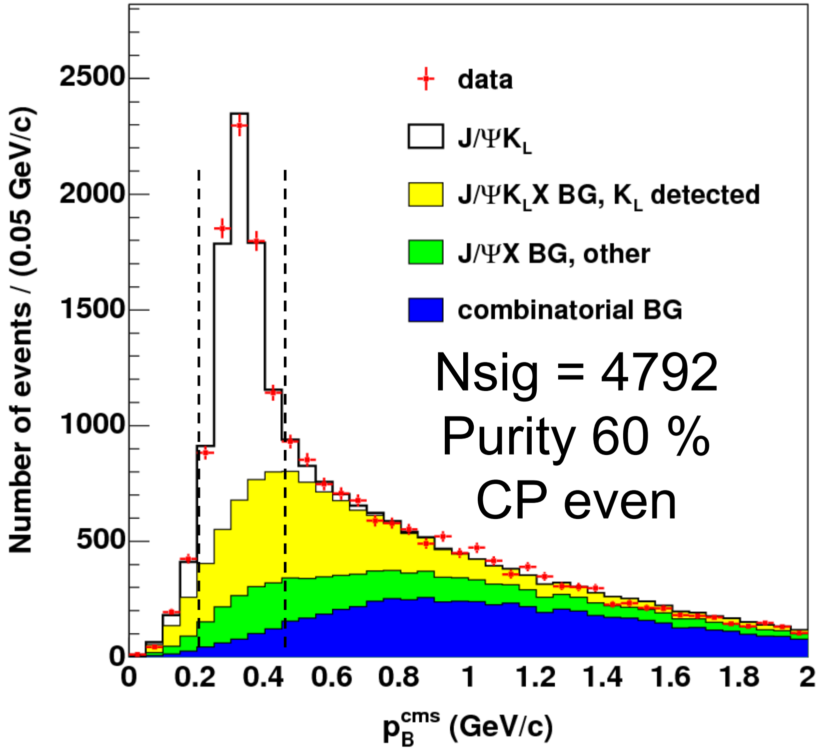
2005: $B^0 \rightarrow J/\psi\ K^0$ with 386 M $B\bar{B}$ pairs

$B^0 \rightarrow J/\psi K_S^0$



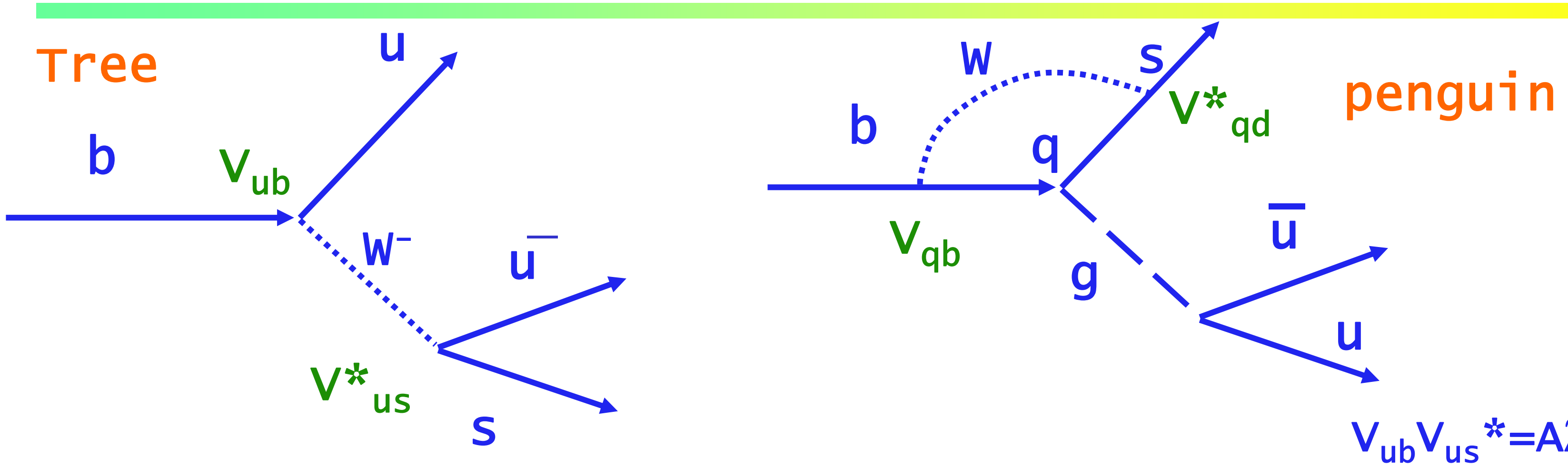
$$M_{bc} = \sqrt{E_{beam}^{*2} - P_{J/\psi Ks}^{*2}}$$

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



p_B^* (momentum in CM)

$K^- \pi^+$ - tree vs penguin



$V_{ub}V_{us}^* = A\lambda^4(\rho - i\eta)$

$V_{cb}V_{cs}^* = A\lambda^2$

Penguin amplitudes for $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ are expected to be equal. Contribution to A(uus) in $K^+\pi^-$ enhanced by λ **in comparison to** $\pi^+\pi^-$

$B \to K^+\pi^-$ tree contribution suppressed by λ^2 vs $\pi^+\pi^-$.

Experiment: $Br(B \to K^+\pi^-) = 1.85\ 10^{-5}$, $Br(B \to \pi^+\pi^-) = 0.48\ 10^{-5}$

$\to Br(B \to \pi^+\pi^-) \sim 1/4\ Br(B \to K^+\pi^-) \to$ penguin contribution must be sizeable

B->$\pi^+ \pi^-$: interpretation

Interpretation:

tree level

tree + 

$$\lambda_{\pi\pi} = e^{2i\phi_2} \quad \rightarrow \quad \lambda_{\pi\pi} = e^{2i\phi_2} \frac{1 + |P/T| e^{i\delta + i\phi_3}}{1 + |P/T| e^{i\delta - i\phi_3}} \equiv |\lambda_{\pi\pi}| e^{2i\phi_{2eff}}$$

strong phase diff. P-T

weak phase (changes sign)

$$A_{\pi\pi} = 0 \quad \rightarrow \quad A_{\pi\pi} \propto \sin\delta$$

$$S_{\pi\pi} = \sin(2\phi_2) \quad \rightarrow \quad S_{\pi\pi} = \sqrt{1 - A^2{}_{\pi\pi}} \sin(2\phi_{2eff})$$

direct $\not{C}P$

$$A(u\bar{u}d) = V_{cb}V_{cd}^*(P_d^c - P_d^t) + V_{ub}V_{ud}^*(T_{u\bar{u}d} + P_d^u - P_d^t) =$$
$$= V_{ub}V_{ud}^* T_{u\bar{u}d}\left[1 + (P_d^u - P_d^t) + (V_{cb}V_{cd}^* / V_{ub}V_{ud}^*)(P_d^c - P_d^t)\right]$$

$$\gamma \equiv \phi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

How to extract ϕ_2, δ and |P/T|?

ϕ_{2eff} depends on δ, ϕ_3, ϕ_2 and |P/T|

$\pi = \phi_1 + \phi_2 + \phi_3$ → ϕ_{2eff} depends on δ, ϕ_1, ϕ_2 and |P/T|

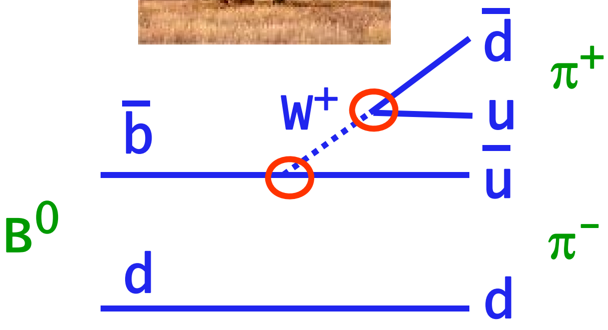
ϕ_1: well measured

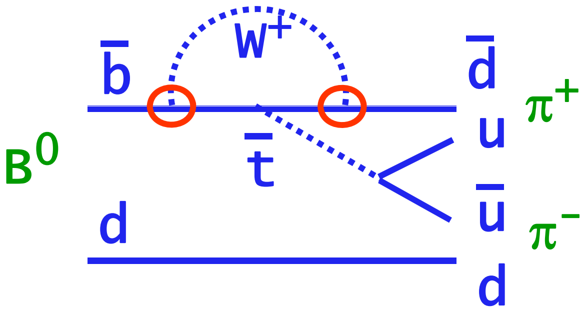
penguin amplitudes $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ are equal
→ limits on |P/T| (~0.3);
considering the full interval of δ values one can obtain interval of ϕ_2 values;

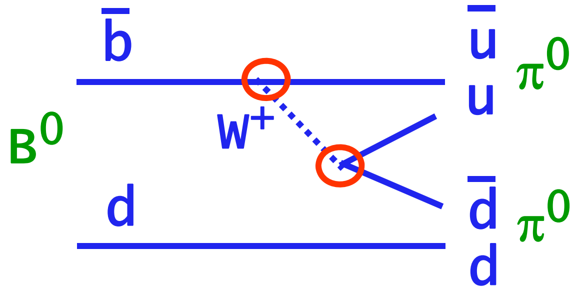
isospin relations can be used to constrain δ
(or better to say $\phi_2 - \phi_{2eff}$);

Extracting ϕ_2: isospin relations

$B^0 \rightarrow \pi^+\pi^-, \pi^0\pi^0$







$T \sim V_{ub}^* V_{ud} \sim \lambda^3$

$P \sim V_{tb}^* V_{td} \sim \lambda^3$

$T_c \sim V_{ub}^* V_{ud}$

No pengiun!

Constraint: relation of decay amplitudes in the SU(2) symmetry

$\bar{A}^{+0} = 1/\sqrt{2}\ \bar{A}^{+-} + \bar{A}^{00}$

$A^{-0} = 1/\sqrt{2}\ A^{+-} + A^{00}$