Experimental Status of B-physics

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1. B-factories
2. QCD and Weak Interaction
   - Inclusive hadronic rates
   - Radiative B decays ($b \to s\gamma$)
3. CP violation and Unitarity Triangle
   - $|V_{ub}|$ and $|V_{cb}|$ ($|V_{td}|$)
   - CP phase β (ϕ_1)
   - Direct CP violations

B-factries

$< e^+e^-$ B-factory accelerators$>$

Symmetric energies (CESR)

$$E_{e^-} = E_{e^+} = \frac{M_{\Upsilon 4S}}{2} = 5.29 GeV$$

Asymmetric energies (PEP-II, KEK-B)

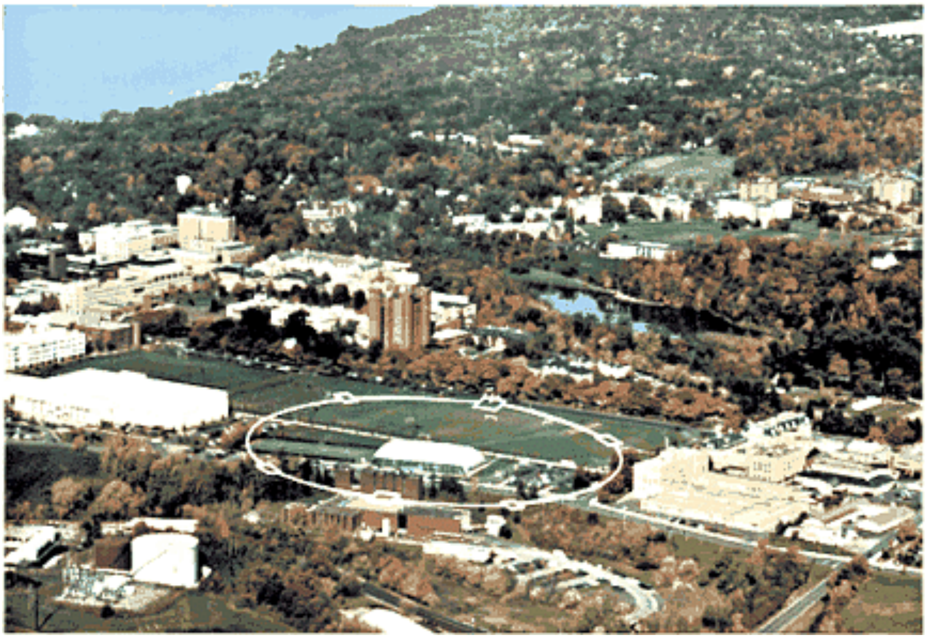
$\Upsilon 4S$ is moving in the lab frame.

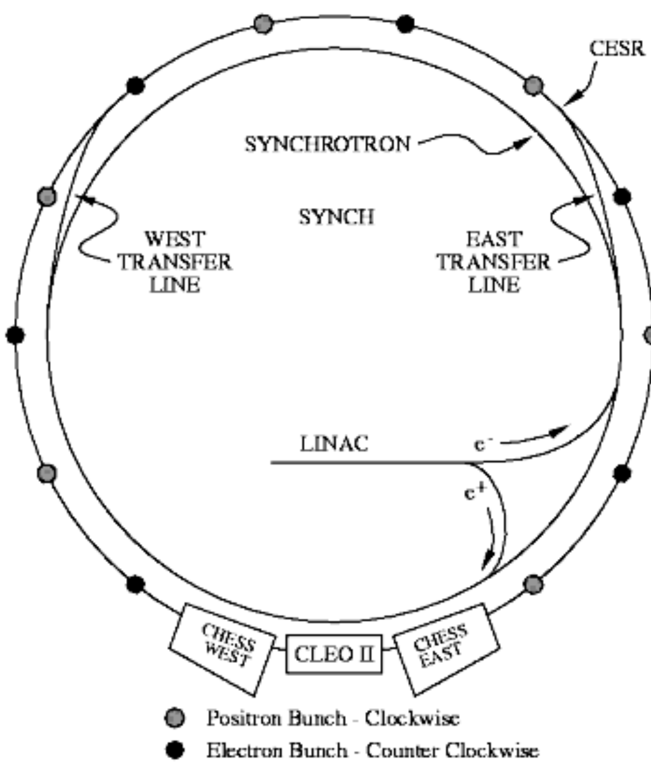
$$E_{\mathrm{CM}} = 2\sqrt{E_{e^+}E_{e^-}} = M_{\Upsilon 4S}$$

$$\begin{cases} E_{\Upsilon 4S} = E_{e^-} + E_{e^+} \\ P_{\Upsilon 4S} = E_{e^-} - E_{e^+} \end{cases}$$

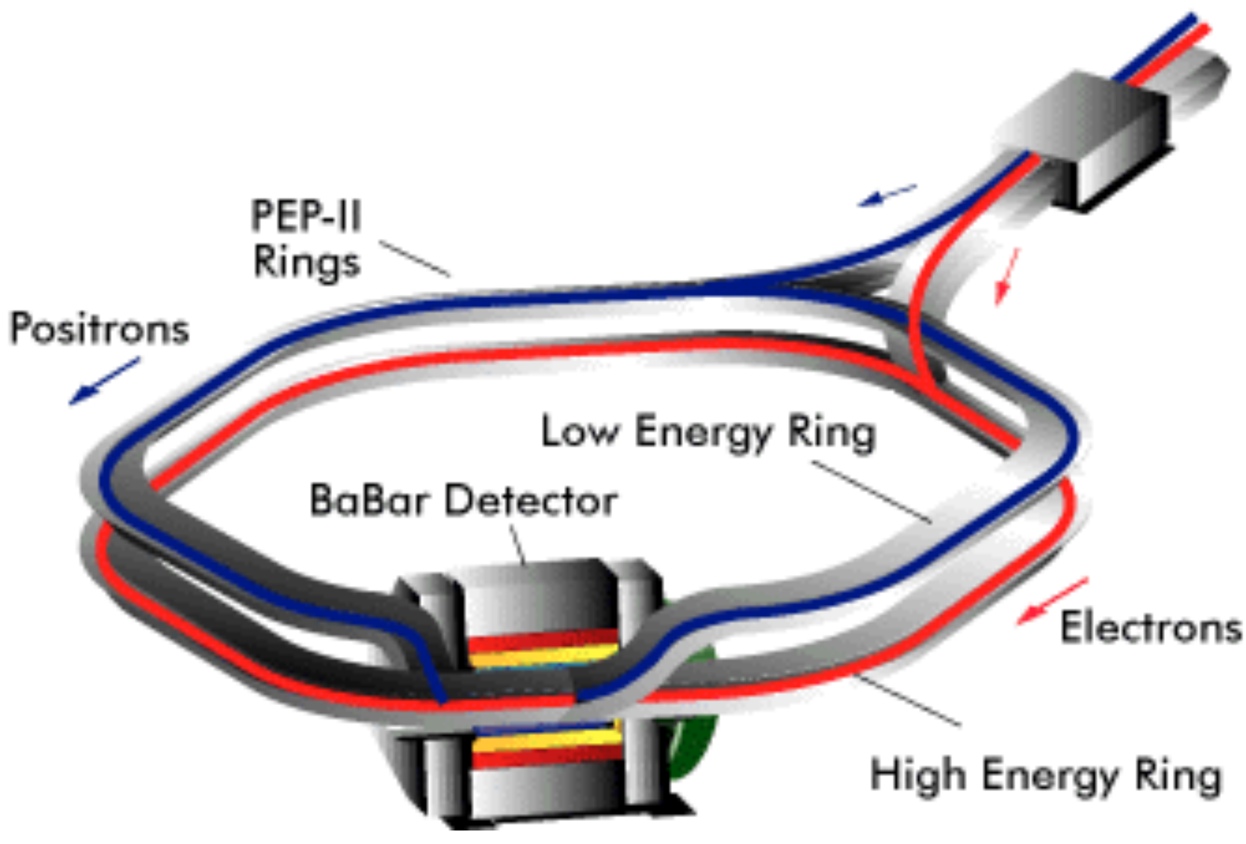
$$\rightarrow \quad \beta_{\Upsilon 4S} = \frac{P_{\Upsilon 4S}}{E_{\Upsilon 4S}} = \frac{E_{e^-} - E_{e^+}}{E_{e^-} + E_{e^+}}$$

CESR (Cornell Electron Strage Ring)

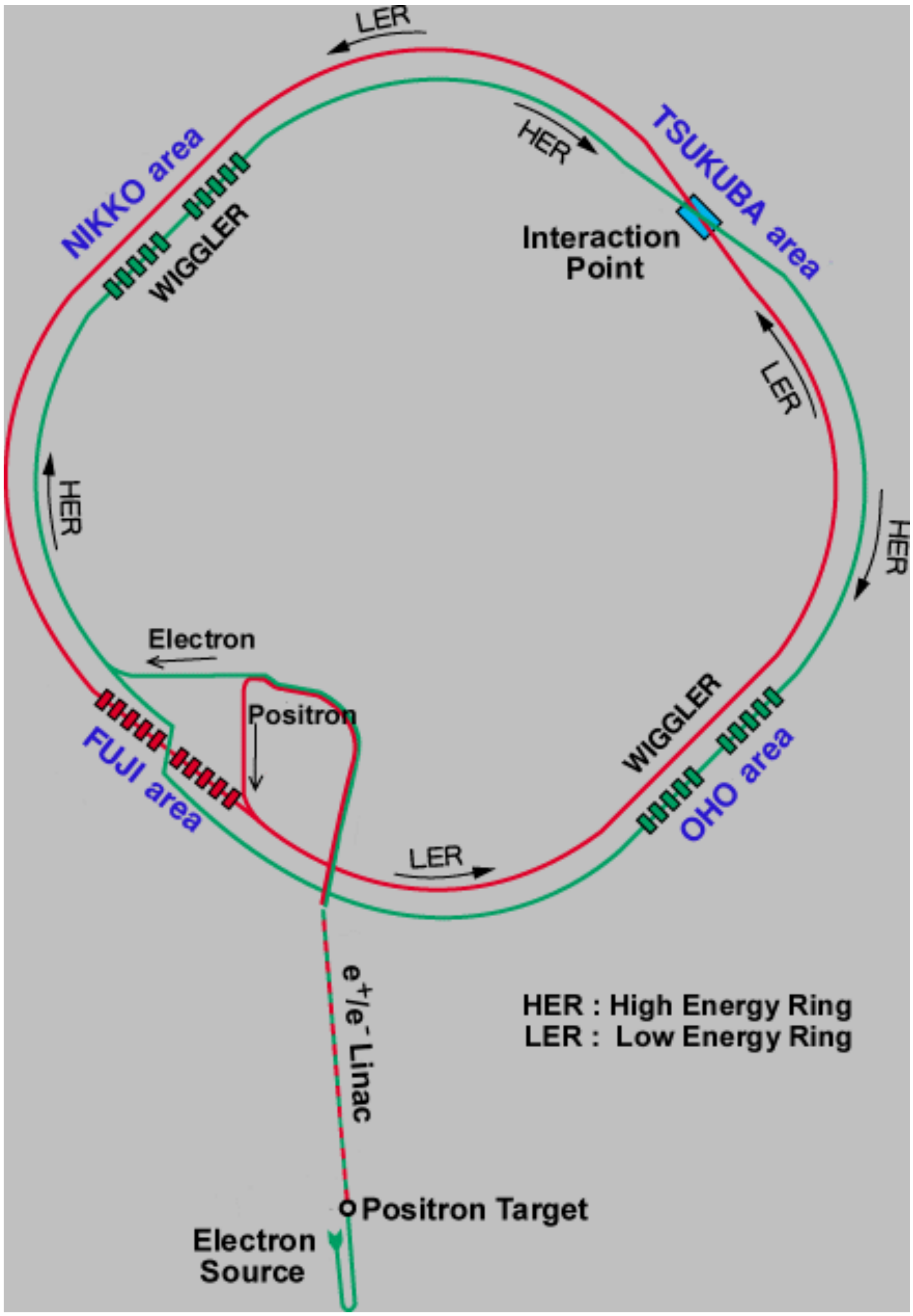




PEP-II (SLAC)


PEP-II
Rings
Positrons
Low Energy Ring
BaBar Detector
Electrons
High Energy Ring

KEK-B (KEK, Japan)



Beam separation

Want collision to occur only at one location

$\rightarrow$ Need for beam separation
(avoid parasitic crossings)

CESR: Pretzel orbit
Interweaving e^+e^- orbits within a single ring
Crossing angle $= \pm 2.3$ mrad

PEP-II: Separation by bending magnet

$$E_{e^+} \neq E_{e^-}$$

$\rightarrow e^+, e^-$ beams bend differently

Head-on collision

KEK-B: Finite-angle crossing
Crossing angle $= \pm 11$ mrad

Large crossing angle

$\rightarrow$ Beam instability (synchro-betatron resonance)
Luminosity reduction (geometrical)

machine	$CESR$	PEP-II	KEK-B
detector	$CLEO$	$BaBar$	$Belle$
circumference (km)	0.768	2.199	3.016
# of rings	1	2	2
E_{e^+}(GeV)	5.3	3.1	3.5
E_{e^-}(GeV)	5.3	9.0	8.0
$\beta_{\Upsilon 4S}$	~ 0	0.49	0.39
$\delta E/E$	6×10^{-4}	7×10^{-4}	7×10^{-4}
Δt_{bunch}	$14ns$	$4.2ns$	$2ns$
bunch size(w)	500μ	181μ	77μ
" (h)	10μ	5.4μ	1.9μ
" (l)	$1.8cm$	$1.0cm$	$0.4cm$
crossing angle(mrad)	± 2.3	0	± 11
Luminosity($cm^{-2}s^{-1}$)	1.5×10^{33}	3×10^{33}	10^{34}
$\#B\bar{B}/s$	1.5	3	10
achievements so far			
Lum(peak)	8×10^{32}	1.5×10^{33}	6×10^{32}
$\int Ldt$ (fb^{-1})	9.2	1.7	0.3

B-factory Status

- CLEO-3 detector currently running with
  a temporary vertex detector.
  To be completed in Feb 2000.

- BaBar and Belle currently running.
  $\sin 2\beta$ result in summer 2000??

Hadronic machines

- HERA-B: wire target inside $e^- - p$ collider at DESY.

  HERA-B beging assembled.
  To be completed Feb 2000.

- CDF/D0: Fermilab $p\bar{p}$ collider.
  Run2 to begin in fall 2000.

Future machines

- LHCb, BTeV, ATLAS, CMS: ~2006 and on.

LEP Finished Z^0 runs - no more B-physics data.
Some B results still to come on the existing data.

Inclusive Hadronic Rates

Two parameters:

1. $B_{\text{s.l.}} \equiv$ average $Br(H_b \to X e^- \nu_e)$

   where $H_b = \begin{cases} \bar{B}^0, B^- & (\Upsilon 4S) \\ \bar{B}^0, B^-, \bar{B}^0_s, N_b(\text{any } b\text{-baryon}) & (Z^0) \end{cases}$

   Expect $B_{\text{s.l.}}(\Upsilon 4S) = \frac{\tau_B}{\tau_b} B_{\text{s.l.}}(Z^0)$

$$B_{\text{s.l.}} = \frac{1}{2.22 + r_{\text{had}}}, \quad r_{\text{had}} = r_{c\bar{u}d} + r_{c\bar{c}s} + r_{\text{no c}}$$

(r_x : rate in unit of $\Gamma_{\text{s.l.}}$)

$$2.22 = 1(e) + 1(\mu) + 0.22(\tau)$$

2. $n_c \equiv$ number of c or $\bar{c}$ per B decay

   Weakly decaying charms: $D^0, D^+, D_s^+, \Lambda_c, \Xi_c$
   Charmonium $\equiv$ 2c if decayed by $c\bar{c}$ annihilation.

   Expect more Λ_c, Ξ_c, and D_s on Z^0.

$$n_c = 1 + Br_{c\bar{c}s} - Br_{\text{no}\,c} = 1 + \frac{r_{c\bar{c}s} - r_{\text{no c}}}{2.22 + r_{\text{had}}}$$

Theoretical estimates of $B_{\text{s.l.}}$ and n_c

Tools

- Local quark-hadron duality

  Σ of final states with certain flavor contents
  $= \Sigma$ of the same flavor contents at quark level

  Assumed to hold at fixed $\sqrt{s}$ of hadronic system ('local' duality)

- pQCD and Heavy-Quark Expansion (HQE)

$$\Gamma(B \to f) = \Gamma_0 \left[a(1 + \frac{\lambda_1}{2m_b^2} + \frac{3\lambda_2}{2m_b^2}) + b\frac{\lambda_2}{m_b^2} + \mathcal{O}(\frac{1}{m_b^3}) \right]$$

$$\left(\Gamma_0 = \frac{G_F^2 m_b^5}{192\pi^3} \right)$$

  a, b: contains CKM factors, Wilson coefficients (pQCD), and phase space factors.

  $\lambda_{1,2}$: 'non-perturbative' effects

  $\lambda_1 = 0 \sim -0.7$ GeV^2: time-delation by fermi motion

  $\lambda_2 = \frac{1}{4}(m_B^{*2} - m_B^2) = 0.12$ GeV^2
  : chromomagnetic effect

  Total effect by $\lambda_{1,2} \sim$ a few % increase.
  Not all non-perturbative effects are included in $\lambda_{1,2}$.

Effects of various corrections affecting $B_{\text{s.l.}}$ and n_c.
(NLO calc by Bagan et. al.)

	naive	NLO($m_c = 0$)	NLO($m_c \neq 0$)
$r_{c\ell\nu}$	2.22	2.22	2.22
$r_{c\bar{u}d}$	3.0	4.0	4.0
$r_{c\bar{c}s}$	1.2	1.6	2.1
$B_{\text{s.l.}}$	0.16	0.13	0.12
n_c	1.16	1.17	1.21
$Br_{c\bar{c}s}$	0.18	0.20	0.25

($r_{\text{no c}} \sim 0.2 \pm 0.1$)

Theoretical estimate of $B_{\text{s.l.}}$ strongly depends on the renormalization scale (also on m_c/m_b).

(Neubert, Sachrajda)

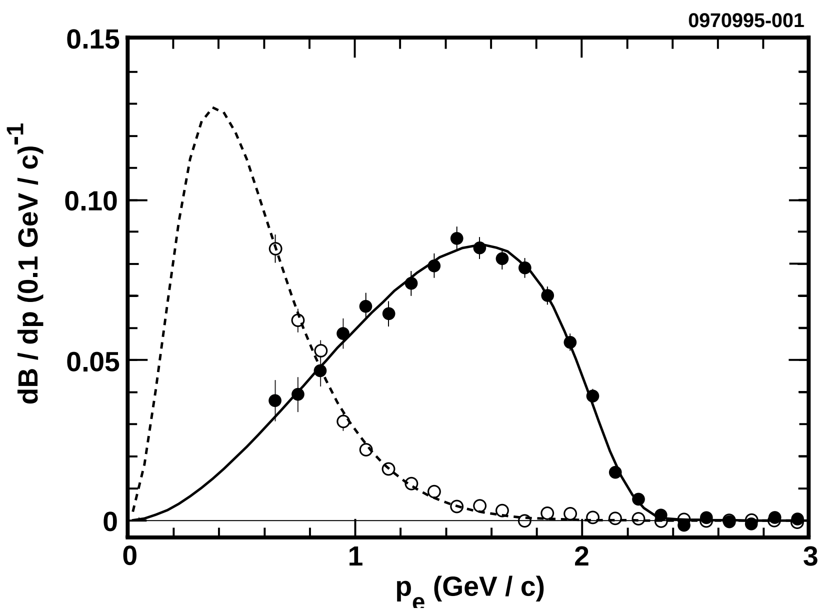
μ/m_b	1	1/2
$B_{\text{s.l.}}$(%)	12.0 ± 1.0	10.9 ± 1.0
n_c	1.20 ± 0.06	1.21 ± 0.06

($m_c/m_b = 0.29$)

Measurements of $B_{\text{s.l.}}$

On $\Upsilon 4S$ (CLEO) - charge correlation method

- Tag one B by high-P lepton (flavor-tagged)
  'The other side': select $b \to e^-$, reject $b \to c \to e^+$.



- Correction for B^0-$\bar{B}^0$ mixing
  Correction for $b \to \bar{c} \to e^-$ ($B \to D\bar{D}X$ etc.)

$$B_{\text{s.l.}} = 10.49 \pm 0.46\% \quad (CLEO).$$

$$B_{\text{s.l.}} = 10.45 \pm 0.21\% \quad (\Upsilon 4S, PDG)$$

$B_{\text{s.l.}}$ on Z^0 (LEP)

Experiment	$B_{\text{s.l.}}(\%)$	method
ALEPH 95	$11.01 \pm 0.10 \pm 0.30$	$1\ell + 2\ell$
L3 96	$10.68 \pm 0.11 \pm 0.46$	e, μ, ν
OPAL 99	$10.83 \pm 0.10 \pm 0.20^{+0.20}_{-0.13}$	(a)
DELPHI 99	$10.65 \pm 0.07 \pm 0.25^{+0.28}_{-0.12}$	(b)

(a) b-tag by lifetime.
Fit two neural-net variables to separate $b \to \ell^-$, $b \to c \to \ell^+$, and backgrounds.

(b) 4 methods

1. $1\ell + 2\ell$
2. b-tag by lifetime/lepton, Fit $p_\ell(B \text{ c.m.})$ and tag-lepton charge correlation.
3. Use all hadronic events + multi-variate fit
4. Similar to 2. Neural net for flavor id.

$$B_{\text{s.l.}} = 10.79 \pm 0.17\% \quad (Z^0 \text{ average}).$$

Measurement of n_c

(%)	CLEO 96	ALEPH 96	OPAL 96	DELPHI 99
D^0	63.6±3.0	60.5±3.6	53.5±4.1	60.05±4.29
D^+	23.5±2.7	23.4±1.6	18.8±2.0	23.01±2.13
D_s^+	11.8±1.7	18.3±5.0	20.8±3.0	16.65±4.50
Λ_c	3.9±2.0	11.0±2.1	12.5±2.6	8.90±3.00
$\Xi_c^{0.+}$	2.0±1.0	6.3±2.1	–	4.00±1.60
$(c\bar{c})$	5.4±0.7	3.4±2.4	–	4.00±1.29
n_c	1.10±0.05	1.23±0.07		1.17±0.09

- Ξ_c: ALEPH and DELPHI used the CLEO measurement of $Br(B \to \Xi_c)$ and added $Br(\Lambda_b \to \Xi_c)$ prediction by JETSET.

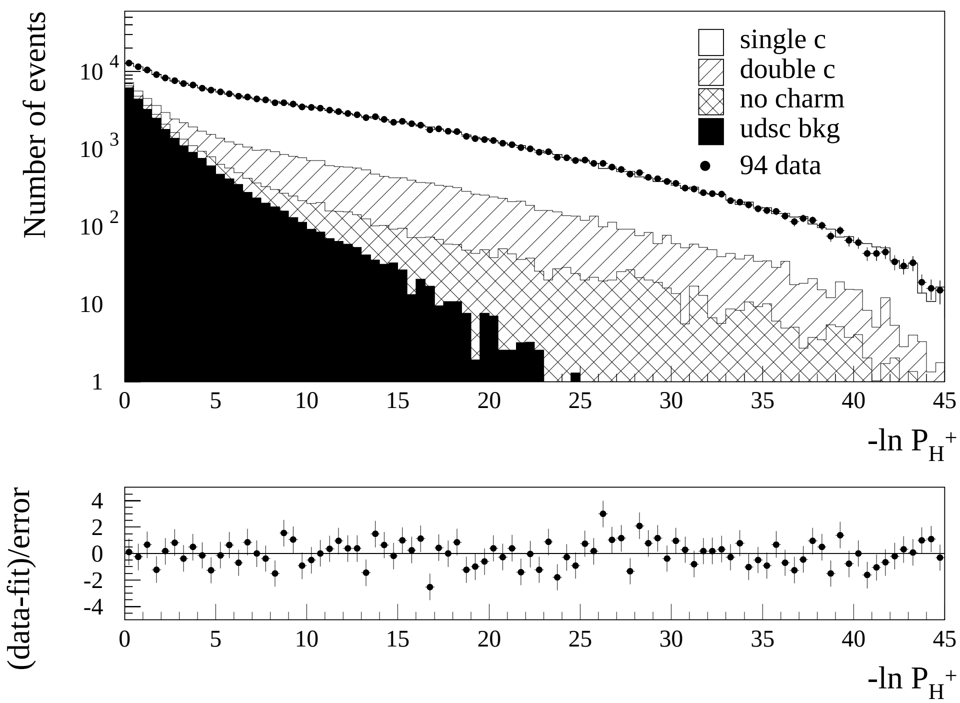
  ALEPH used an old (wrong) CLEO number for $Br(B \to \Xi_c)$ ($n_c : 1.23 \to 1.21$)

- DELPHI values for $\Xi_c^{0.+}$ and $(c\bar{c})$ + OPAL
  $\to$ $n_c = 1.14 \pm 0.08$

Charm counting by vertexing (DELPHI)

Does not depend on charm decay Br's.

Fit P_H^+ (probability that all tracks with positive lifetime comes from the primary vertex)



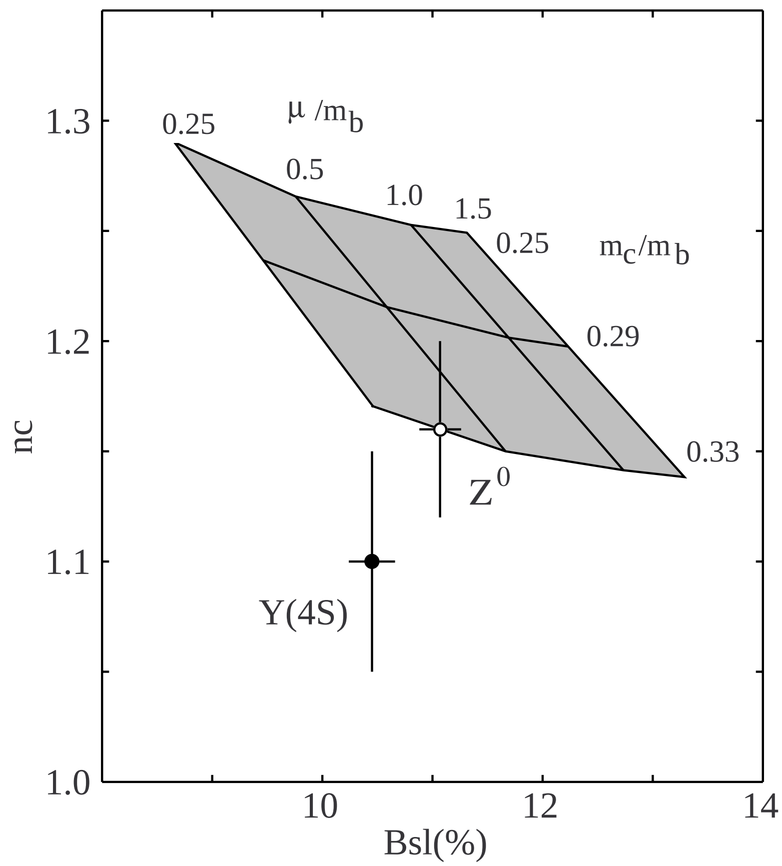
Find numbers of 0,1,2-charm decays

$$n_c = 1.147 \pm 0.041 \pm 0.008 \quad (DELPHI)$$

LEP average:

$$n_c = 1.16 \pm 0.04 \quad (Z^0)$$

$B_{\text{s.l.}}$ vs n_c. Theory vs experiments.



1. $B_{\text{s.l.}}$ for Z^0 is converted to $\Upsilon 4S$ value ($\times\tau_B/\tau_b$)

2. Discrepancy between theory and $\Upsilon 4S$ values is alarming. Boosting $r_{\text{no c}}$ will fix it.

3. Theory and Z^0 values are consistent.

Radiative B Decays ($b \to s\gamma$)

Triumph of OPE/pQCD

Relevant Hamiltonian for $b \to s\gamma(g)$:
(use unitarity to factor out $V_{tb}V_{ts}^*$)

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{i=1,2,7,8} C_i(\mu) O_i(\mu)$$

$$O_1 = (\bar{c}_{L\beta}\gamma^\mu b_{L\alpha})(\bar{s}_{L\alpha}\gamma_\mu b_{L\beta})$$
$$O_2 = (\bar{c}_{L\alpha}\gamma^\mu b_{L\alpha})(\bar{s}_{L\beta}\gamma_\mu b_{L\beta})$$
$$O_7 = \tfrac{e m_b}{16\pi^2}\bar{s}_\alpha \sigma^{\mu\nu}(1+\gamma_5) b_\alpha F_{\mu\nu}$$
$$O_8 = \tfrac{g_s m_b}{32\pi^2}\bar{s}_\alpha \sigma^{\mu\nu}(1+\gamma_5)\lambda^a_{\alpha\beta} b_\beta G^a_{\mu\nu}$$

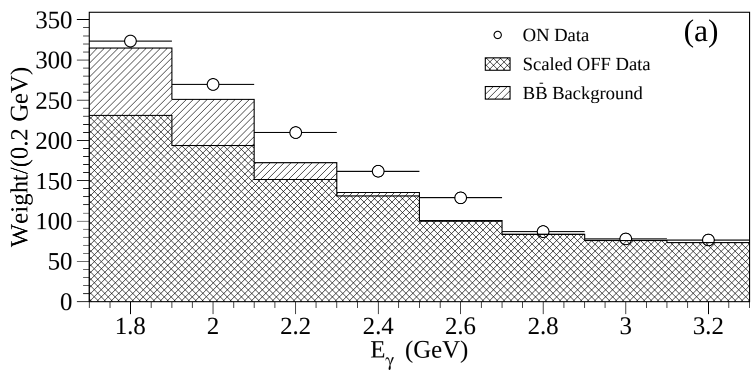
The lowest level: O_7 only.
QCD correction enhances the rate by ~ 3.

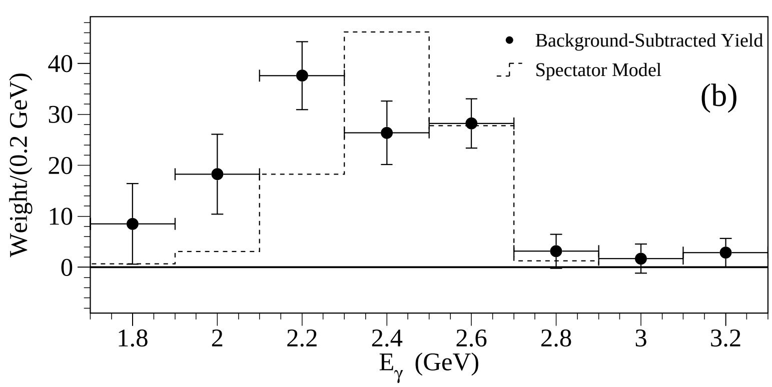
- Complete NLO (order α_s) calculation done.
- Scale dependence ~20% (LO) $\to$ ~5%(NLO).
- 'Non perturbative effects' ($\lambda_{1,2}$) $\sim +3\%$.

$b \to s\gamma$ **CLEO** (3 fb^{-1})

Look for an excess of single photon at the B decay end point ($2.1 < E_\gamma < 2.7$ GeV)

Suppress continuum bkg by 'pseudo B reconstruction': $\gamma + 1K^{0,+} + n^+\pi^\pm + n^0\pi^0$ ($n^+ + n^0 \le 4, n^0 \le 1$) that is consistent with B





Dotted line: shape predicted for $m_b = 4.88$ GeV and Fermi motion $p_B = 250$ MeV (model dep.)

CLEO

$$Br(b \to s\gamma) = (3.15 \pm 0.35 \pm 0.32 \pm 0.26 \quad) \times 10^{-4}$$

stat sys model

ALEPH

$$Br(b \to s\gamma) = (3.11 \pm 0.80 \pm 0.72) \times 10^{-4}$$

Theory

$$Br(b \to s\gamma) = (3.28 \pm 0.33) \times 10^{-4}$$

Agreement is excellent.

'Pseudo B reconstruction' $\to$ b flavor tag.
Mistag rate ∼8% (CLEO)

$$-0.09 < A_{CP} \equiv \frac{b - \bar{b}}{b + \bar{b}} < 0.42$$

$$\text{or} \;\; A_{CP} = (+0.16 \pm 0.14 \pm 0.05) \times (1 \pm 0.04)$$

mistag

Prospect: CLEO has 3× more data
→ soon to produce a result.

Exclusive $B \to X_{s,d}\gamma$ (CLEO)

- $B^+ \to K^{*+}\gamma$, $B^0 \to K^{*0}\gamma$

$$K^{*+} \to K^+\pi^0, K^0\pi^+$$
$$K^{*0} \to K^+\pi^-, K^0\pi^0$$

$$\frac{B \to K^*\gamma}{B \to X_s\gamma}, \quad A_{CP}(\text{small in SM}).$$

- $B \to K_2^*(1430)\gamma$
  The same final states as K^* above.

- $B \to (\rho/\omega)\gamma$

$$\frac{Br(B \to (\rho/\omega)\gamma)}{B(B \to K^*\gamma)} = \xi \left|\frac{V_{td}}{V_{ts}}\right|^2$$

ξ: SU(3) breaking, phase space, long-distance

<Full reconstruction on $\Upsilon 4S$ >

$$B \to f_1 \cdots f_n$$

Energy and absolute momentum of B known:

$$E_B = E_{\text{beam}} = 5.290 \text{ GeV}$$
$$|\vec{P}_B| = \sqrt{E_{\text{beam}}^2 - M_B^2} = 0.34 \text{ GeV/c}$$

$\rightarrow$ require that candidates satisfy

$$E_{\text{tot}} = E_{\text{beam}}\,, \quad |\vec{P}_{\text{tot}}| = |\vec{P}_B|$$

where

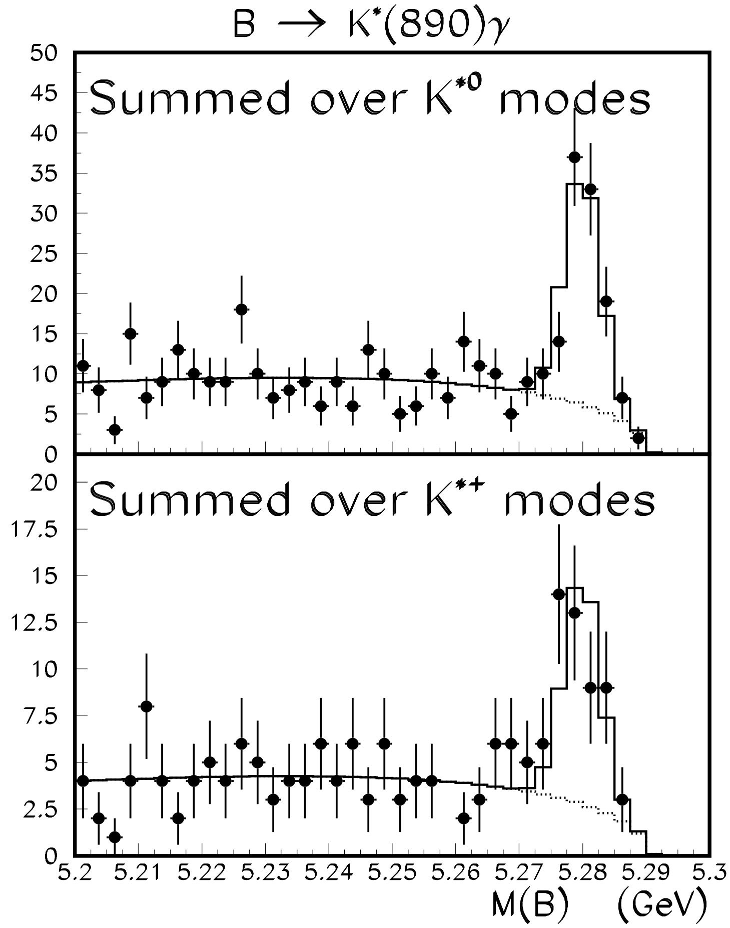
$$E_{\text{tot}} \equiv \sum_{i=1}^{n} E_i\,, \quad \vec{P}_{\text{tot}} \equiv \sum_{i=1}^{n} \vec{P}_i$$

Instead of E_{tot} and $|\vec{P}_{\text{tot}}|$, we historically use

$\Delta E \equiv E_{\text{tot}} - E_B$ (energy difference)

$M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - \vec{P}_{\text{tot}}^2}$ (beam-constrained mass)

$B \to K^*\gamma$ (CLEO)

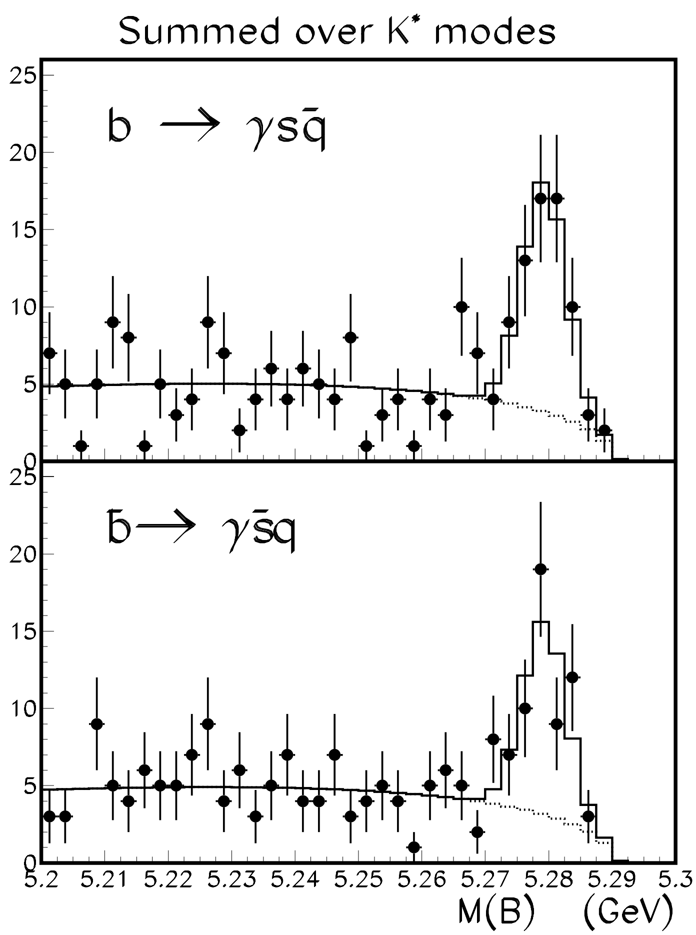


$$Br(B^0 \to K^{*0}\gamma) = (4.550^{+0.715}_{-0.683} \pm 0.343) \times 10^{-5}$$

$$Br(B^+ \to K^{*+}\gamma) = (3.764^{+0.893}_{-0.831} \pm 0.284) \times 10^{-5}$$

$B \to K^*\gamma$ A_{CP} **(CLEO)**

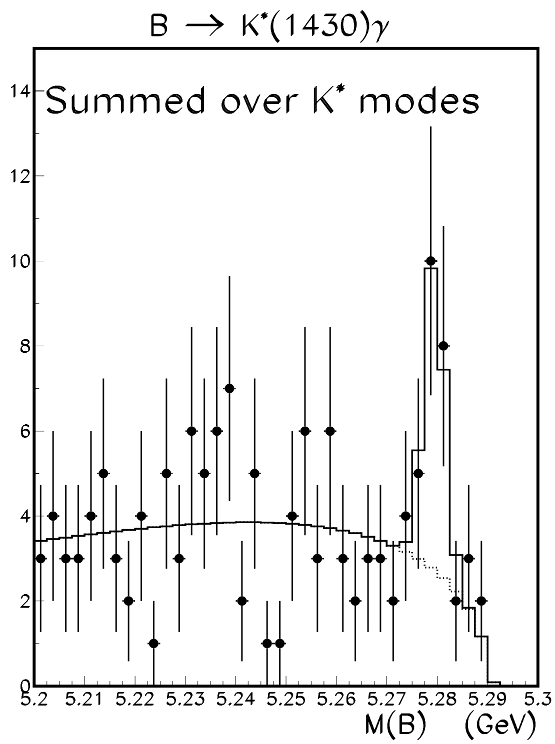
All modes other than $K^0\pi^0$ are flavor-tagged.



$$A_{CP} = +0.080 \pm 0.125 \quad (SM \sim 1\%)$$

$B \to K_2^*(1430)\gamma$ **(CLEO)**

$Br(K_2^*(1430)(J=2) \to K\pi) \sim 50\%$



$K^*(1410)(J=1)$ not excluded.

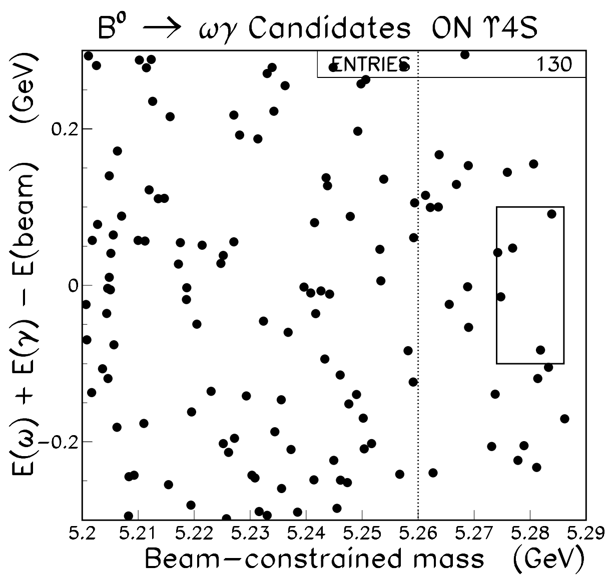
Assuming all $K_2^*(1430)$,

$$Br(B \to K_2^*(1430)\gamma) = (1.7 \pm 0.5 \pm 0.1) \times 10^{-5}$$

$$R \equiv K_2^*(1430)\gamma \;/\; K^*(890)\gamma = 0.4 \pm 0.1$$

$$R = \begin{cases} 3.0 - 4.9 \text{ (Ali,Ohl,Mannel 93)} \\ 0.4 \pm 0.2 \text{ (Veseli, Olsson 96)} \end{cases}$$

$B \to (\rho\omega)\gamma$ (CLEO)



Upper limits (90% c.l. 1996)

$$Br(B^0 \to \omega\gamma) < 1 \times 10^{-5}$$
$$Br(B^0 \to \rho^0\gamma) < 4 \times 10^{-5}$$
$$Br(B^- \to \rho^-\gamma) < 1 \times 10^{-5}$$

$$\to |V_{td}/V_{ts}|^2 < 0.45 \sim 0.56$$

Updated limit will come soon (3.5 times data).

Unitarity Triangle

Standard-Model quark-W Interaction

$$H_{\text{int}}(t) = \int d^3x \, [\mathcal{H}_{qW}(x) + \mathcal{H}^{\dagger}_{qW}(x)]$$

$$\mathcal{H}_{qW}(x) = \frac{g}{\sqrt{2}}(\bar{u}, \bar{c}, \bar{t})_L \, V_{CKM} \, \gamma_\mu \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L W^\mu$$

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \quad \begin{pmatrix} \text{CKM matrix} \\ \text{unitary} \end{pmatrix}$$

If one can adjust CP phases of quarks such that

$$(CP)\mathcal{H}_{qW}(x)(CP)^\dagger = \mathcal{H}^\dagger_{qW}(x') \quad (x' = (t, -\vec{x}))$$

$$\rightarrow \quad (CP)H_{\text{int}}(t)(CP)^\dagger = H_{\text{int}}(t)$$

$$S = \sum_n \frac{(-i)^n}{n!} \int dt_1 \cdots dt_n T(H_{\text{int}}(t_1) \cdots H_{\text{int}}(t_n))$$

$$\rightarrow \quad (CP)S(CP)^\dagger = S$$

- Then, the transition amplitude of $|i\rangle \rightarrow |f\rangle$ becomes the same as that of $CP|i\rangle \rightarrow CP|f\rangle$:

$$\langle f|S|i\rangle = \langle f|(CP)^\dagger \underbrace{(CP)S(CP)^\dagger}_{S}(CP)|i\rangle = \langle f|(CP)^\dagger S(CP)|i\rangle$$

I.e., same amp. if particle$\leftrightarrow$antiparticle and helicity flip in the initial and final states.

- Or, if $|i\rangle$ and $|f\rangle$ are eigen states of CP:

$$CP|i\rangle = \eta_i|i\rangle\,, \quad CP|f\rangle = \eta_f|f\rangle\,,$$

Then,

$$\langle f|S|i\rangle = \eta_f^*\eta_i\langle f|S|i\rangle\,;$$

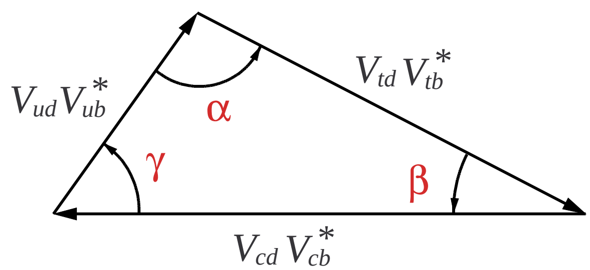
I.e., no transition unless $\eta_f^*\eta_i = 1$ or $\eta_f = \eta_i$.
CP eigenvalue is conserved.

In general, a 3×3 unitary matrix has one non-trivial phase that cannot be rotated away by adjusting the CP phases of quarks. $\rightarrow$ CPV.

A Main Question of the CPV Study in B: 'Is V_{CKM} unitary?'

e.g: orthogonality of d-column and b-column:

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



$$\alpha(\phi_2) \equiv \arg\left(\frac{V_{td}V_{tb}^*}{-V_{ud}V_{ub}^*}\right), \beta(\phi_1) \equiv \arg\left(\frac{V_{cd}V_{cb}^*}{-V_{td}V_{tb}^*}\right)$$

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

Note: the definitions of α, β, γ are independent of quark phases.

For **any** 3 complex numbers a, b, c, by defintion,

$$\text{arg}(\frac{c}{-a}) + \text{arg}(\frac{b}{-c}) + \text{arg}(\frac{a}{-b}) = \pi \ (\text{mod} 2\pi)$$

regardless of $a + b + c = 0$ or not.

It does not test the unitarity.
It tests angles measured are as defined or not.
(e.g. due to penguine contamination etc.)

Need also to measure the lengths of the sides for unitarity test.

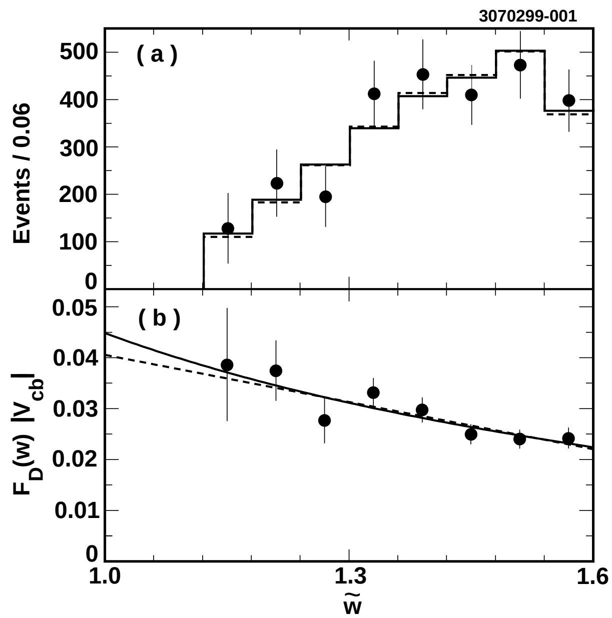
Measurement of $|V_{cb}|$ (CLEO) (1999)

$$B \to D^{0,+}\ell\nu$$

$$\frac{d\Gamma}{dw} = \frac{G_F^2|V_{cb}|^2 F_D(w)^2}{48\pi^3}(m_B + m_D)^2 m_D^3 (w^2-1)^{3/2}$$

w: γ-factor of D in B frame.

$F_D(1) = 1$ in the HQ limit.



$$Br(\bar{B}^0 \to D^+\ell\nu) = 2.09 \pm 0.13 \pm 0.18\%$$

$$Br(B^- \to D^0\ell\nu) = 2.21 \pm 0.13 \pm 0.19\%$$

$$|V_{cb}|F_D(1) = 0.0416 \pm 0.0047 \pm 0.0037$$

$$|V_{cb}| = 0.042 \pm 0.005 \pm 0.004 \pm 0.004$$

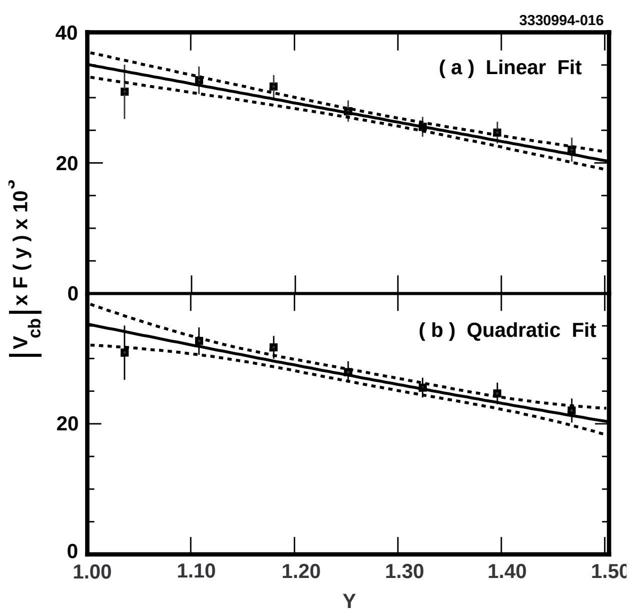
$(F_D(1) = 1.0 \pm 0.1)$

$B \to D^{*0,+}\ell\nu$ (CLEO) (1995)

$$\frac{d\Gamma}{dw} = \frac{G_F^2|V_{cb}|^2 F(w)^2}{48\pi^3}(m_B + m_{D^*})^2 m_D^{*3}$$
$$\times\sqrt{w^2-1}\left[4w(w+1)\frac{1-2wr+r^2}{(1-w)^2} + (w+1)^2\right]$$

$$r = m_{D^*}/m_B$$

$F(1) = 1$ in the HQ limit.



$$|V_{cb}|F(1) = 0.0351 \pm 0.0019 \pm 0.0018$$
$$|V_{cb}| = 0.0383 \pm 0.0021 \pm 0.0020 \pm 0.0011$$

New preliminary Br's:

$$Br(\bar{B}^0 \to D^{*+}\ell\nu) = 4.91 \pm 0.17 \pm 0.42\%$$
$$Br(B^- \to D^{*0}\ell\nu) = 5.13 \pm 0.54 \pm 0.64\%$$

New DELPHI result ON $B \to D^{*+}\ell\nu$ (1999)

$$Br(B^0 \to D^{*+}\ell\nu) = 5.22 \pm 0.12 \pm 0.55\%$$
$$|V_{cb}|A(1) = 0.0380 \pm 0.0013 \pm 0.0016$$
$$|V_{cb}| = 0.0417 \pm 0.0015 \pm 0.0017 \pm 0.0014$$
$$(A_1(1) \sim F(1) = 0.91 \pm 0.03)$$

LEP combined result on $|V_{cb}|$:

Inclusive	$(40.8 \pm 0.4 \pm 2.0) \times 10^{-3}$
Exclusive	$(38.4 \pm 2.5 \pm 2.2) \times 10^{-3}$
average	$(40.2 \pm 1.9) \times 10^{-3}$

- The agreement between exclusive and inclusive indicates validity of global quark-hadron duality.

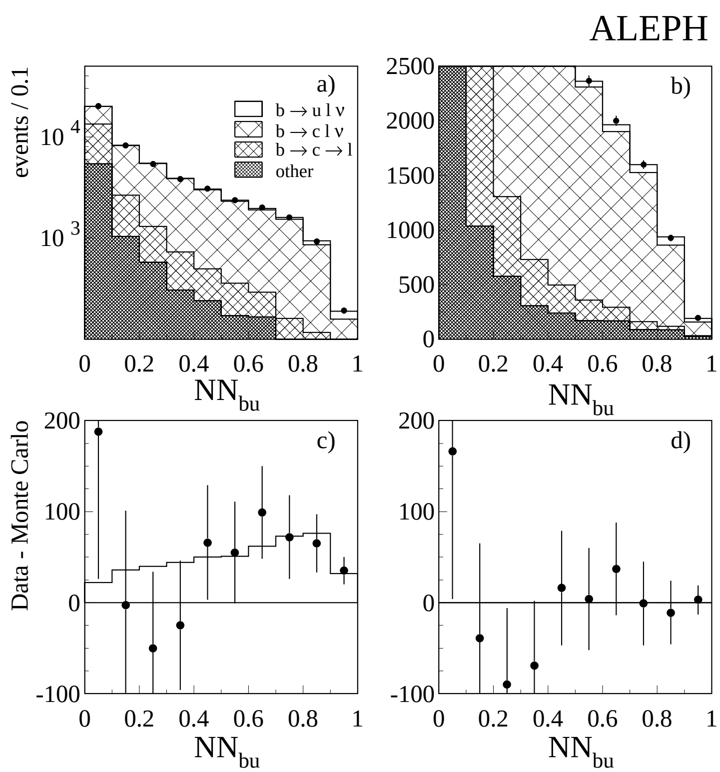
- $D^*\ell\nu$ has more yield near $w = 1$ than $D\ell\nu$ $\to$ less model dependence.

Inclusive $b \to u\ell\nu$ measurements at LEP

ALEPH, DELPHI, L3 combined

$$Br(b \to u\ell\nu) = (1.67 \pm 0.35 \pm \underset{\text{model}}{0.38} \pm 0.20\ ) \times 10^{-3}$$

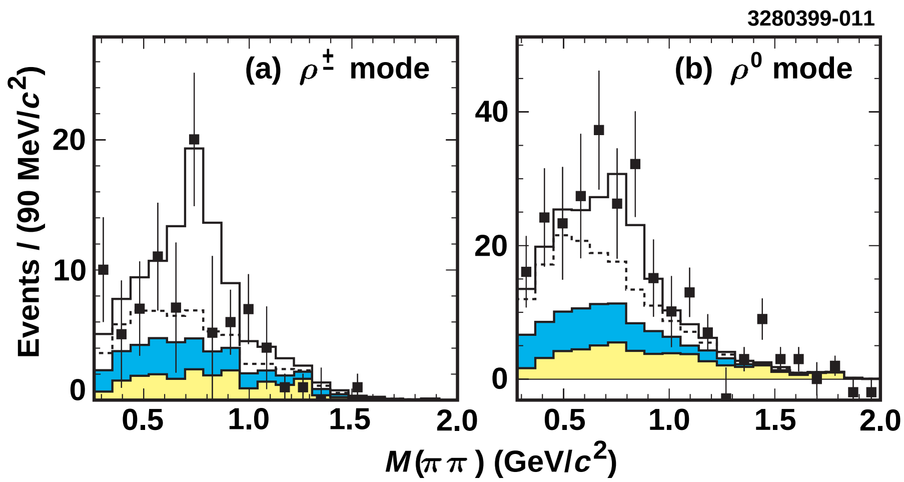
$$|V_{ub}| = \left(4.05^{+0.39+0.43+0.23}_{-0.46\,-0.51\,-0.27} \pm \underset{\tau_B}{0.02} \pm \underset{\text{Theory}}{0.16}\right) \times 10^{-3}$$



NN_{bu}: neural net variable
(even shape, charged multiplicity, invariant mass etc.)

Exclusive $B \to \rho^- \ell \nu$ measurements by CLEO

Sensitivity is at high lepton energy
($E_\ell > 2.3$ GeV)



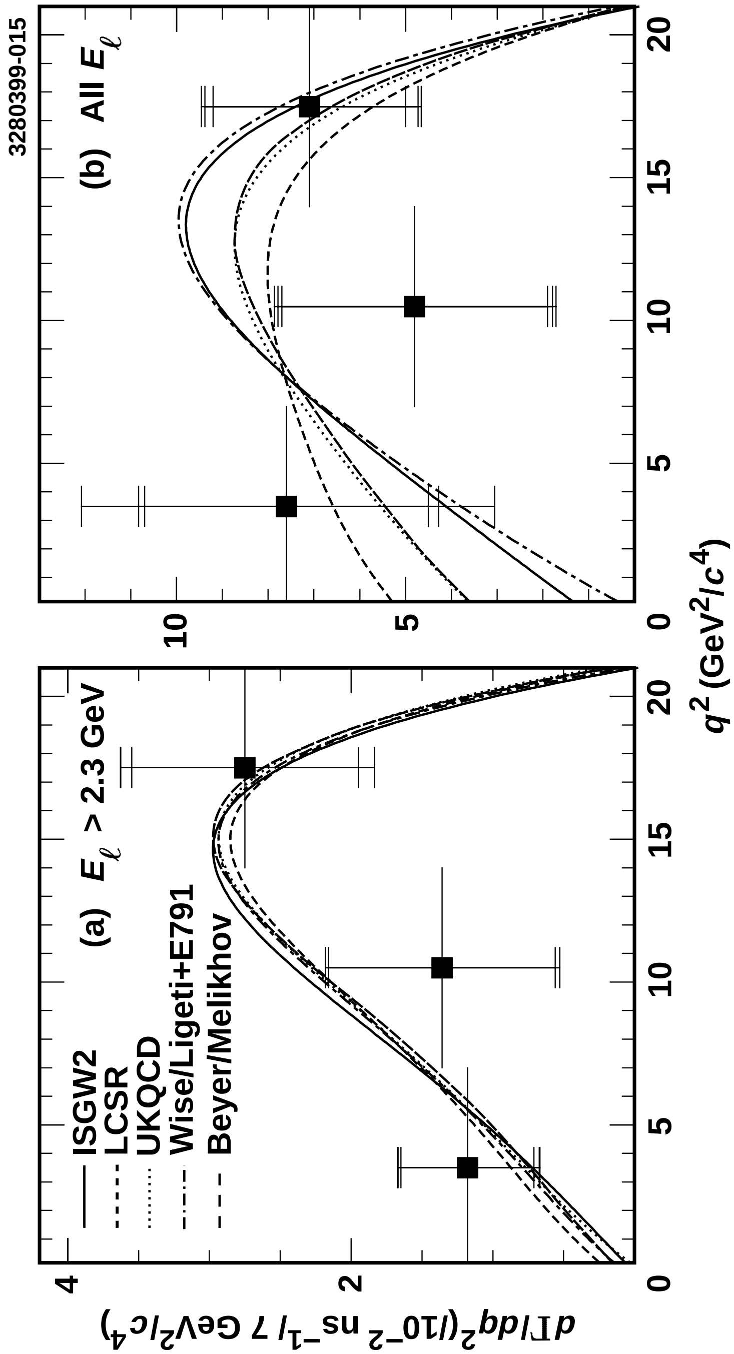
Combining with the old results

$$Br(B \to \rho^- \ell \nu) = (2.57 \pm 0.29^{+0.33}_{-0.46} \pm 0.41) \times 10^{-4}$$

$$|V_{ub}| = (3.25 \pm 0.14^{+0.21}_{-0.29} \pm 0.55(th.)) \times 10^{-3}$$

$$(\rho \ell \nu + \pi \ell \nu)$$

CLEO $B \to \rho\ell\nu$



B-mixing ($|V_{td}|$)

$$\chi \equiv \frac{B(t=0) \to barB(\text{at decay})}{B(t=0) \to \text{all}} = \frac{1}{2}\frac{x^2}{1+x^2}$$

$$x \equiv \frac{\Delta m}{\Gamma}, \quad (\Gamma = (1.6ps)^{-1})$$

$$\Delta m_d = \frac{g^4}{192\pi^2 m_W^2}|V_{tb}|^2|V_{td}|^2 f_{B_d}^2 B_{B_d}^2 \eta_B f(m_t)$$

- Measure the mixing rate $\chi \to |V_{td}|$.

Large theoretical uncertainties (f_{B_d} and B_{B_d})

- Or, measure B_d mixing and B_s mixing:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2 \xi^2 \frac{\eta_{B_s}}{\eta_{B_d}}$$

Less theoretical uncertainty, but
Δm_s not measured yet:

$$\Delta m_s > 14.3 \text{ ps}^{-1}$$

A New CLEO Measurement of B_d Mixing (Preliminary)

On $\Upsilon 4S$:

$$\chi = \frac{\text{Both decay as } B + \text{Both decay as } \bar{B}}{\text{All}}$$

- One side: lepton tag
- The other size: partial reconstruction of

$$B \to D^{*+} n\pi \,, D^{*+} \to D^0 \pi^+$$

$\vec{v}(D^*) \sim \vec{v}(\pi^+)$ allows the reconstruction of $B \to D^{*+} n\pi$ without D^0.

	mixed	unmixed
e-tag	210 ± 17	838 ± 30
μ-tag	191 ± 16	626 ± 26

Correct for mistags

$$\chi_d = 19.7 \pm 1.3\%$$