Measurements of CKM matrix elements, $|V_{cb}|$ and $|V_{ub}|$ in B decays

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Outline

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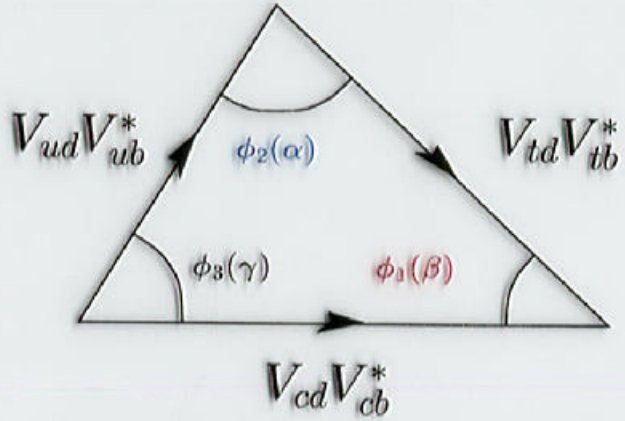
- Conclusions

Introduction



- The CKM matrix element must be determined experimentally.
- To mesure the lengths of the sides of the unitarity triangle is important for confirming the CKM scheme as the mechanism for CP violation
- Many opportunities to measure CKM elements in B decays

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & \lambda^2 A \\ \lambda^3 A(1 - \rho - i\eta) & -\lambda^2 A & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

$|V_{cb}|$ Measurements

- $|V_{cb}|$ is the third most precise measured value after $|V_{ud}|, |V_{us}|$
- The uncertainty in $|V_{cb}|$ is improtant in determining the constraint on the unitarity triangle from ϵ_K

$$\epsilon_K \propto A^4 = \frac{|V_{cb}|^4}{\lambda^8}$$

- $|V_{cb}|$ can be determined in several ways using
  - Inclusive semileptonic rate
  - The partial rate for $B \to D^{(*)}\ell\nu$ in the reigon of the phase space where $D^{(*)}$ is at rest in the B rest frame (HQET)
  - The total rate for exclusive as $B \to D^{(*)}\ell\nu$

$|V_{cb}|$ from Inclusive Semileptonic Decay

Measurement of $\mathcal{B}(B \to X\ell\nu)$: existing results

- Single-lepton measurement : CLEO Phys.Rev.D45 (1992)

Model	e(%)	μ(%)	$e+\mu$ fit(%)
ACCMM	10.5±0.2±0.3	$10.7 \pm 0.7 \pm 0.7$	$10.5 \pm 0.2 \pm 0.4$
ISGW	10.1±0.2±0.3	$9.7 \pm 0.3 \pm 0.6$	$9.9 \pm 0.1 \pm 0.4$
ISGW**	11.1±0.3±0.3	$11.7 \pm 0.6 \pm 0.7$	$11.2 \pm 0.3 \pm 0.4$

- Di-lepton measurement
  - ARGUS Phys.Lett B318 (1993) : (9.6±0.5±0.4)% @246pb^{-1}
  - CLEO Phys.ReV.Lett 76 (1996) : (10.49±0.17±0.43)% @2.06fb^{-1}

Single-lepton Measurements (Preliminary)

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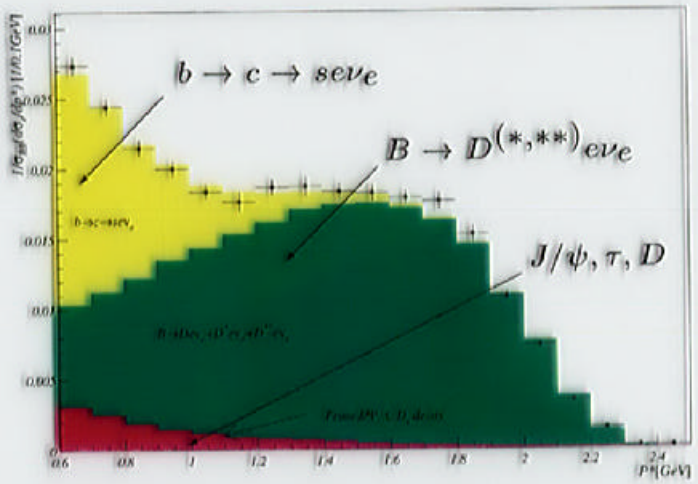
- Single-e measurement @3.0fb^{-1}

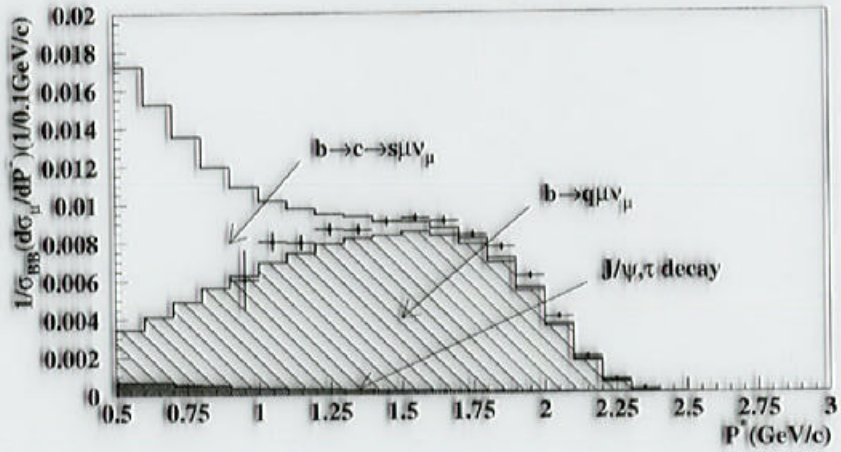
  $\mathcal{B}(B \to X e \nu_e) = 10.54 \pm 0.12^{+0.83}_{-0.65}$ (%)

- Single-μ measurement @5.8fb^{-1}

  $\mathcal{B}(B \to X \mu \nu_\mu) = 10.94 \pm 0.10 \pm 0.62$ (%)



Electron momentum spectrum fitted by ISGW



Muon momentum spectrum

Di-lepton Measurements @5.1fb^{-1}

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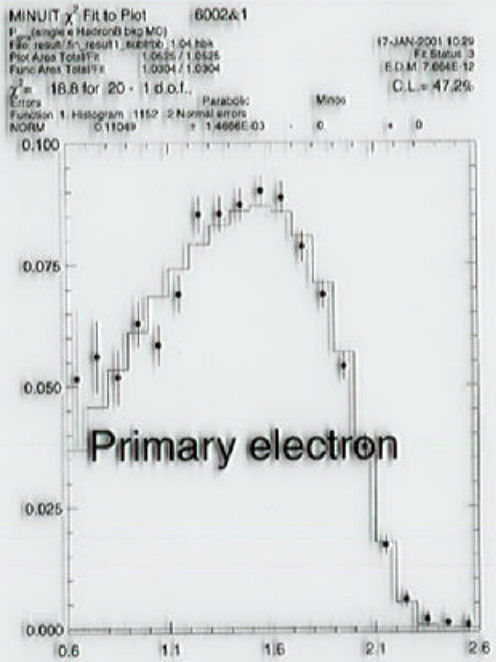

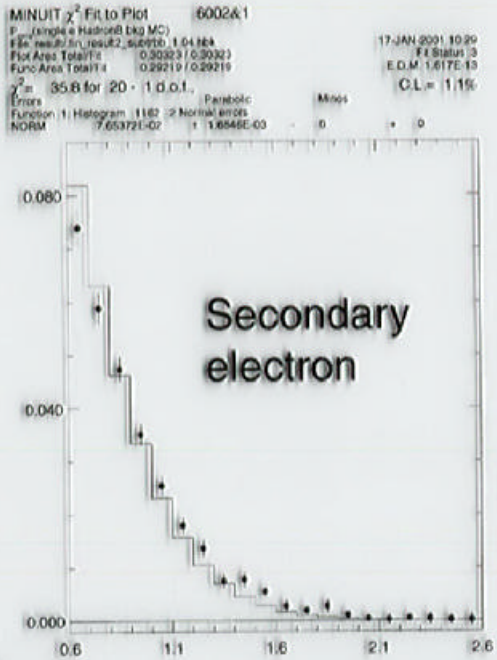

- $B\bar{B}$ events tagged with high momentum (muon / electron): $1.5 < P^* < 2.2$ (GeV/c)
- Primary & secondary leptons can be separated using the charge & kinematic correlations btn tag lepton and electron
- $B\bar{B}$ mxing & mis-tagging are corrected for

$|V_{cb}|$ from Di-lepton Measurements (Preliminary) Belle

- Branching fraction : $\mathcal{B}(B \to X e \nu_e) = (11.05 \pm 0.15 \pm 0.46)\%$

$$\boxed{|V_{cb}|^2 = \frac{\mathcal{B}(B \to X l \nu)}{(\tau_B \cdot \gamma_c)}}$$

$$\tau_B = 1.607 \pm 0.021 \text{ (PDG2000)}$$

Model	γ_c	$\|V_{cb}\| \times 10^{-2}$
ACCMM	40 ± 8	$4.15 \pm 0.09 \pm 0.26$
ISGW**	42 ± 8	$4.05 \pm 0.09 \pm 0.24$
M.Shifman *et al.*	41.3 ± 4	$4.08 \pm 0.09 \pm 0.12$
P.Ball *et al.*	43.2 ± 4.2	$3.99 \pm 0.09 \pm 0.12$

$|V_{cb}|$ from End Point of $B \to D^{(*)}\ell\nu$ Decay

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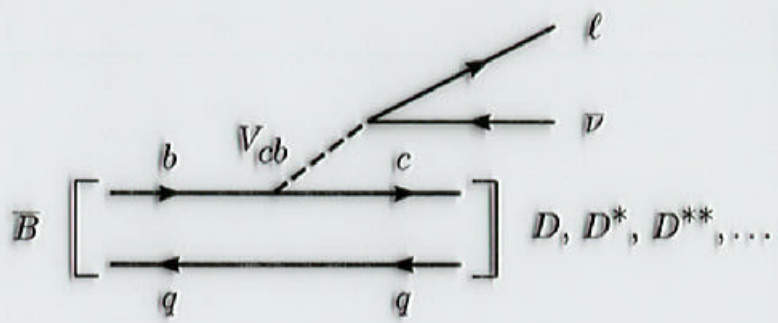

- $B \to D^{(*)}\ell\nu$ decay depends on $|V_{cb}|$ & strong interaction effect, where is parametrized by form factors: $F_{D^{(*)}}(y)$
- HQET offers calculation of the kinematic point $F_{D^{(*)}}(y \to 1)$ which $D^{(*)}$ is at rest with respect to the B

$$q^2 = M_{w^*}^2 = (p_\ell + p_\nu)^2 = (p_{\bar{B}} - p_{D^{(*)}})^2$$

$$y = v_{\bar{B}} \cdot v_{D^{(*)}} = \frac{M_{\bar{B}}^2 + M_{D^{(*)}}^2 - q^2}{2M_{\bar{B}}M_{D^{(*)}}}$$

- Measure $\frac{d\Gamma}{dy}$ and extrapolate to obtain the rate at y=1.
- The rate at y=1 $\propto |V_{cb}|F(1)$

$B \to D\ell\nu$: Full Reconstruction Method @5.8fb^{-1}

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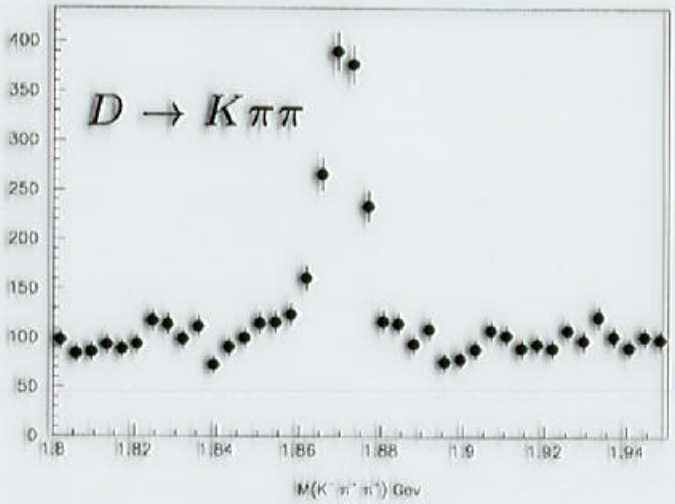

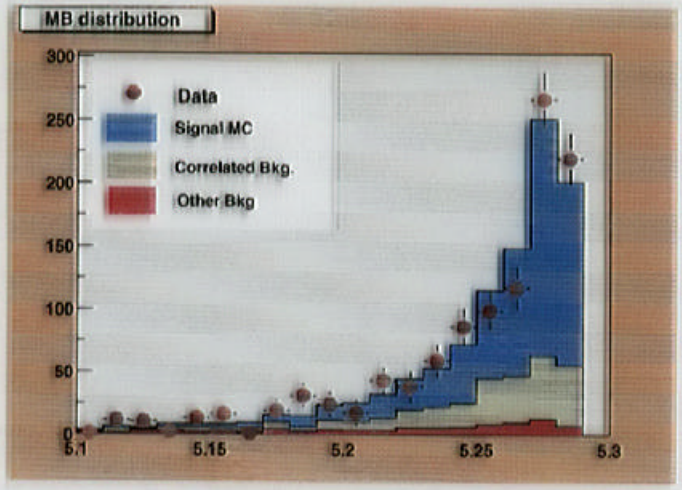

- Missing 4-momentum reconstruction

$$E_{\rm Miss} \equiv 2E_{\rm beam} - \Sigma E_i$$

$$\vec{p}_{\rm Miss} = -\Sigma \vec{p}_i$$

Raw yield	1213±34.8
combinatoric	424±20.6
correlated	192.6
uncorrelated	16.8
continuum	22.0
fake lepton	4.3
Final Yield	553.3±40.5

$|V_{cb}|$ from $B \to D\ell\nu$ Decay (Preliminary)

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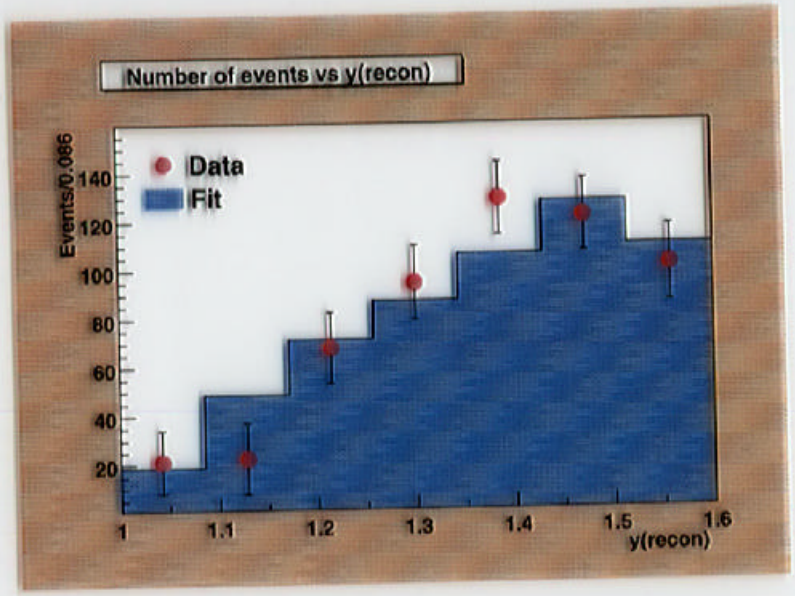
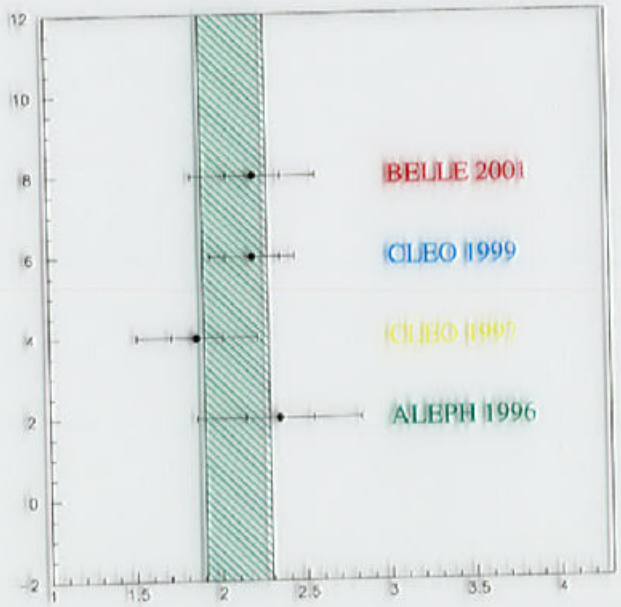


- By integration of $d\Gamma/dy$ over y with results from $|V_{cb}|$ fit,
  $\mathcal{B}(B \to D\ell\nu) = (2.21 \pm 0.16 \pm 0.33)\%$



- $|V_{cb}|F(1) = (4.42 \pm 0.48 \pm 0.35) \times 10^{-2}$
- $\rho^2 = 0.89 \pm 0.14 \pm 0.06$
- Using $F(1) = 1.0 \pm 0.07$

$$|V_{cb}| = (4.42 \pm 0.48 \pm 0.35 \pm 0.30) \times 10^{-2}$$

$B \to D^* \ell \nu$: Partial Reconstruction Method @5.8fb^{-1}

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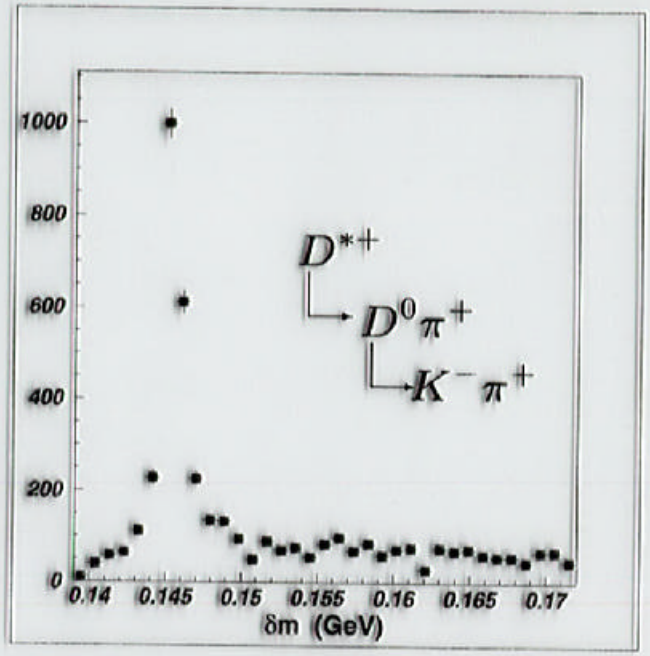

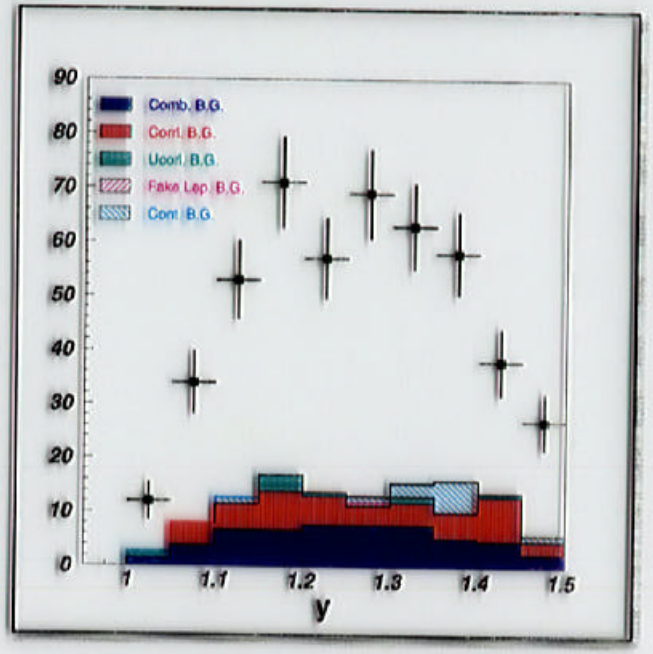

- Partial reconstruction using $D^* \ell$ pairs

$$P^2_{\text{Miss}} \equiv (P_B - P_{D^*\ell})^2$$

$$M^2_{\text{Miss}} = M^2_B + M^2_{D^*\ell} - 2E_B E_{D^*\ell}$$

- Background subtraction

  Combinatoric B.G $\to$ δm sideband

  $0.155 < \delta m < 0.165$

  Correlated B.G : $B \to D^{**} \ell \nu$

$|V_{cb}|$ from $B \to D^* \ell \nu$ Decay (Preliminary)

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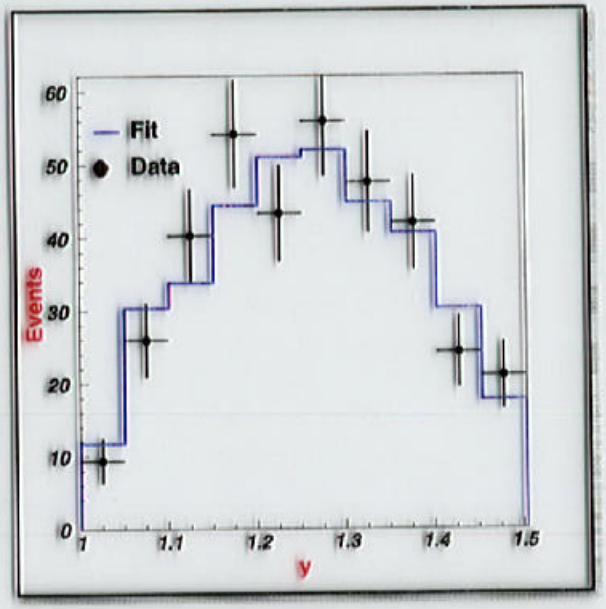
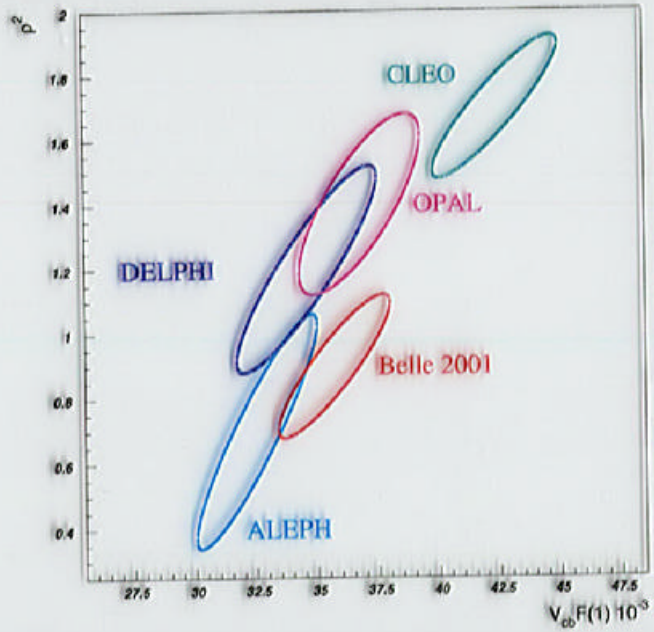


EXP	$\|V_{cb}\|F(1) \times 10^{-3}$	ρ^2
ALEPH	$32.5 \pm 2.1 \pm 1.3$	$0.7 \pm 0.3 \pm 0.2$
DELPHI	$34.6 \pm 1.4 \pm 2.6$	$1.2 \pm 0.1 \pm 0.3$
OPAL	$36.8 \pm 1.7 \pm 1.8$	$1.4 \pm 0.2 \pm 0.2$
CLEO	$42.4 \pm 1.8 \pm 1.9$	$1.7 \pm 0.1 \pm 0.2$
Belle	$35.7 \pm 1.9 \pm 1.3$	$0.9 \pm 0.1 \pm 0.2$



- $\mathcal{B}(B \to D^* \ell \nu) = (4.58 \pm 0.45 \pm 0.34)\%$
- Using $F(1) = 0.913 \pm 0.042$,
  $|V_{cb}| = (39.1 \pm 2.0 \pm 1.5 \pm 1.6) \times 10^{-3}$

$|V_{ub}|$ Measurements

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- The determination of $|V_{ub}|$ is important since CPV cannot be accomodated in the minimal SM if $|V_{ub}| = 0$

- $|V_{ub}|$ can be determined by following ways
  - Endpoint of lepton spectrum for $b \to c$ transitions in inclusive semileptonic B decays
    Uncertainties in extrapolation from small endpoint($\sim 20\%$)
    $|V_{ub}| = (4.1 \pm 0.9) \times 10^{-3}$
  - Exclusive semileptonic decays $B \to X\ell\nu$ where $X = \pi, \rho$ & ω
    Model dependence in extrating $|V_{ub}|$ from form factors ($\sim 20\%$)
    $|V_{ub}| = (3.3 \pm 0.2^{+0.3}_{-0.4} \pm 0.7) \times 10^{-3}$
  - Exclusive non-leptonic decays $B \to D_s^{(*)} X_u$
    Model dependence from factorization, form factor($f_{D_s^{(*)}}$)
    No measurement yet

Analysis of $B \to \pi \ell \nu$ @5.8fb^{-1} (Preliminary)

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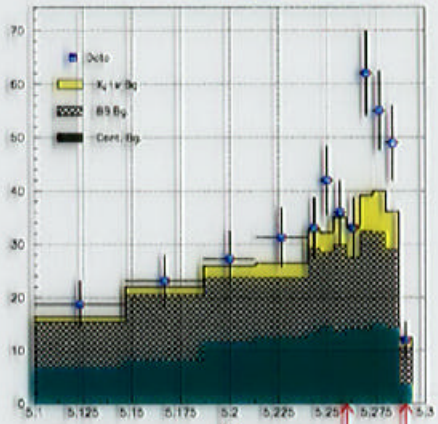
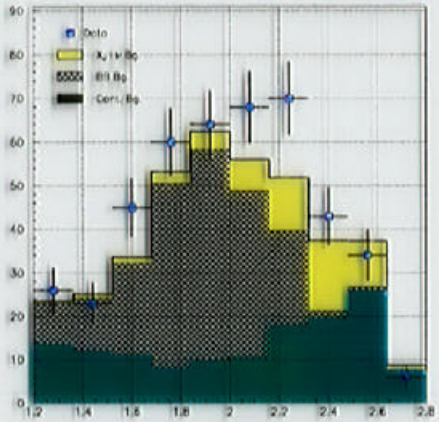
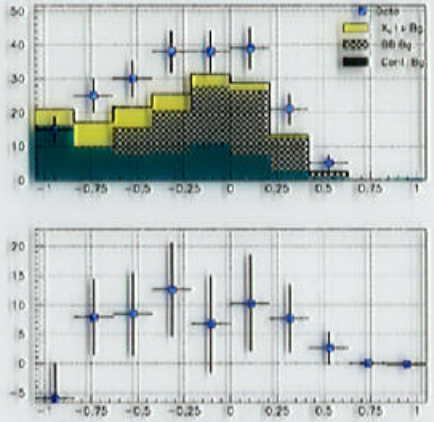


M_B after ΔE cut



P_ℓ^*



Cos of lepton in W^*

- Full reconsrtruction method using $E_{\rm Miss}, \vec{P}_{\rm Miss}$
- $\Delta E \equiv E_{\rm beam} - (E_\pi + E_\ell + E_\nu)$
- Branching fraction : $\mathcal{B}(B \to \pi \ell \nu) = (1.05 \pm 0.31 \pm 0.35) \times 10^{-4}$

Analysis of $B \to D_s X_u$ @11fb^{-1}

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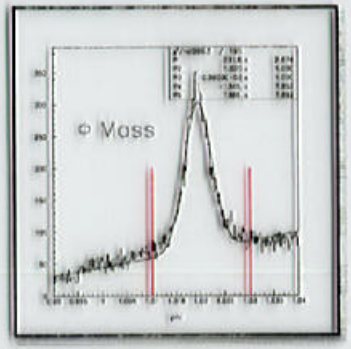
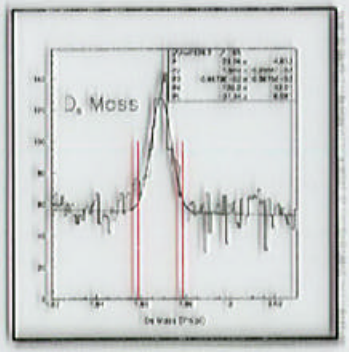
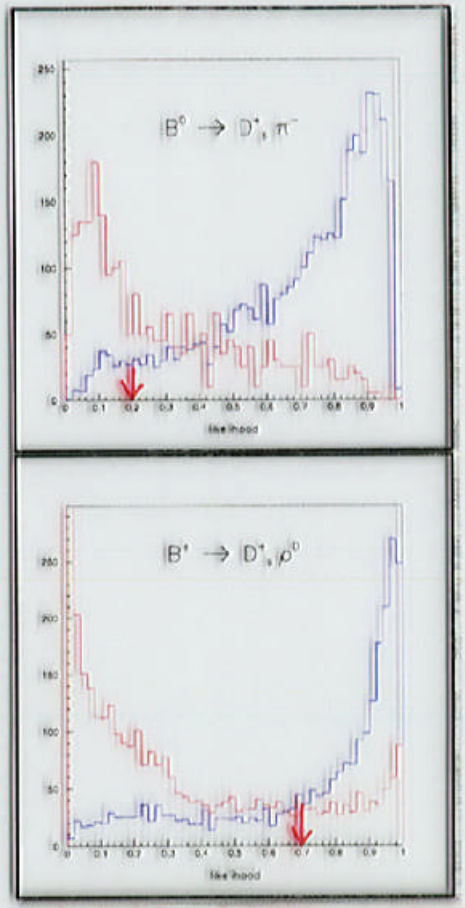
$B \to D_s X_u$ ($X_u : \pi, \rho^0$)

$\hookrightarrow \phi\pi^{\pm}$ (3.6%)







Likelihood (SFW, $\cos\theta_B$)

Analysis of $B \to D_s X_u$ (Preliminary)

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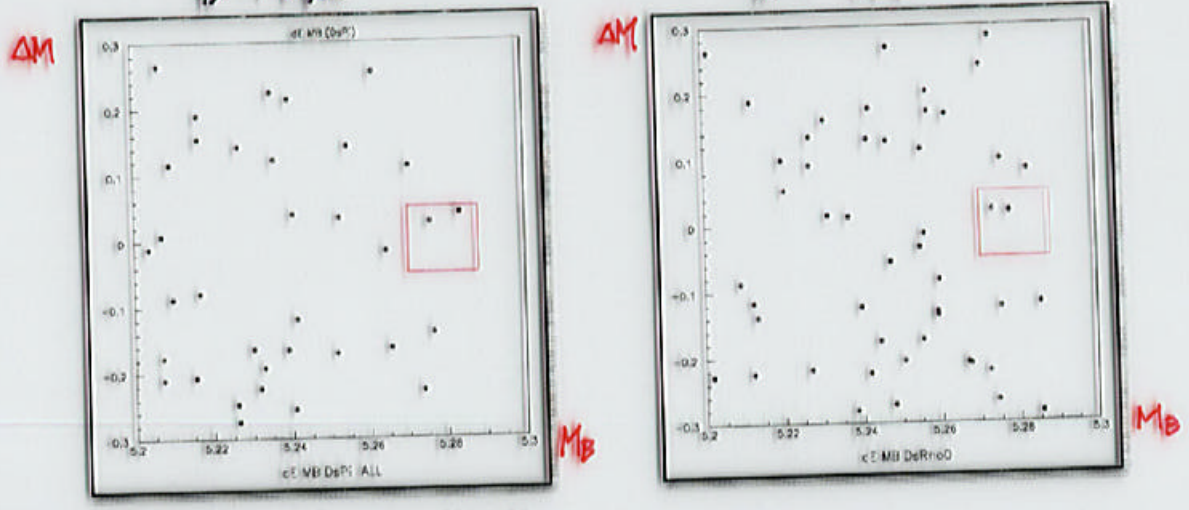

- Branching fraction Upper limit:

$$2.0 \times 10^{-4} \text{ for } \mathrm{D_s}\pi$$
$$4.3 \times 10^{-4} \text{ for } \mathrm{D_s}\rho$$

at 90% CL

- $|V_{ub}|$ Upper limmit:

$$\mathcal{B}(B^0 \to D_s^+ \pi^-) = (2.6 \sim 4.8) \times |V_{ub}^* V_{cs}|^2 \to |V_{ub}| < 0.009$$

T. Kurimoto's paper

Conclusions

- Preliminary $|V_{cb}|$ measurements from different methods

Method	$\|V_{cb}\| \times 10^{-2}$
Di-lepton	$4.06 \pm 0.09_{\rm exp} \pm 0.19_{\rm theory}$
$B \to D^* \ell \nu$	$3.91 \pm 0.19_{\rm exp} \pm 0.16_{\rm theory}$
$B \to D \ell \nu$	$4.42 \pm 0.59_{\rm exp} \pm 0.30_{\rm theory}$

- Each approach in $|V_{cb}|$ measurements is complementary and consistent

- Analyses for $|V_{ub}|$ are making progress