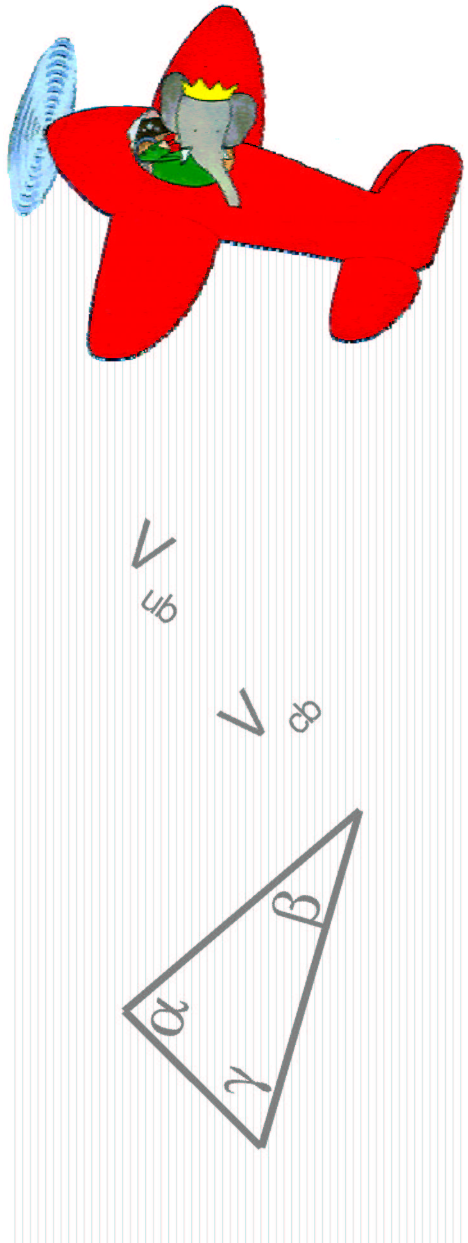

Measurement of the CKM Matrix Element $|V_{ub}|$ with *BABAR*

ICHEP 2002 Amsterdam

Parallel Session
CP Violation and the CKM Matrix

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for the *BABAR* Collaboration

Outline of the Presentation

Part I

– Inclusive versus Exclusive Measurements
– *BABAR* Dataset

Part II

– Inclusive Endpoint-Spectrum Analysis
– Preliminary Result

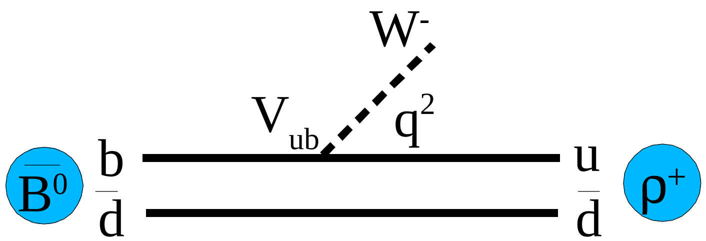
Part III

– Exclusive $B \to \rho\, e\, \nu$ Analysis
– New Preliminary Result

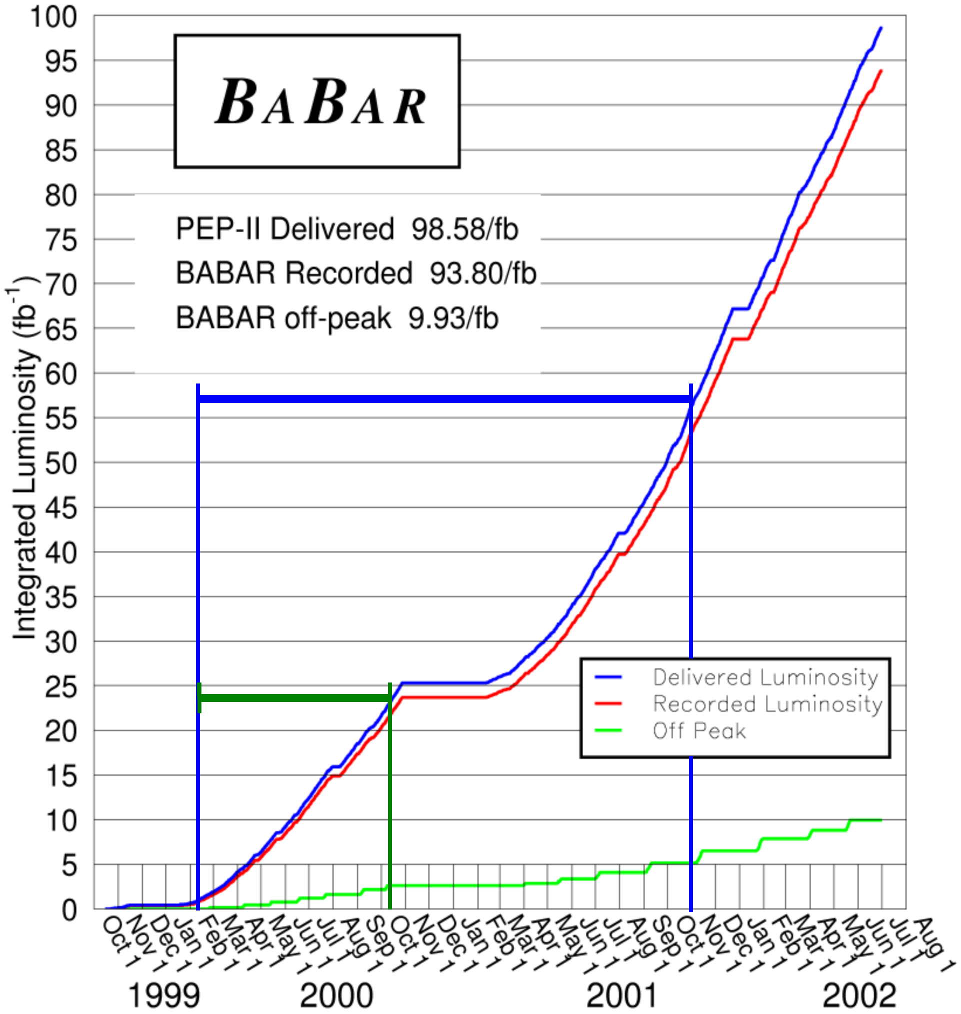
Inclusive vs. Exclusive Measurement of $|V_{ub}|$

- **Inclusive:**
  - blind to decay channel
  - due to large $b \to c\, e\, \nu$ backgrounds only sensitive in a small lepton energy region
  - need to extrapolate visible rate to total rate, introducing large model dependencies
  - can use inclusive photon spectrum $b \to s\gamma$ to measure Fermi motion and reduce extrapolation uncertainty
  - need Operator Product Expansion and b-quark mass to extract $|V_{ub}|$ from the total rate.

- **Exclusive:**
  - reconstruct selected modes
  - sensitive in larger lepton energy region, due to kinematical constraints
  - need form-factors to describe the transition of the B meson to a light meson
  - uncertainty of the form-factor normalization introduces large model dependency



The *BABAR* Data Set



Data Sets used:

Inclusive Analysis:

L_{on} = 20.6 fb^{-1}

L_{off} = 2.6 fb^{-1}

$N_{B\bar{B}}$ = 22.6 x 10^{6}

Exclusive Analysis:

L_{on} = 50.5 fb^{-1}

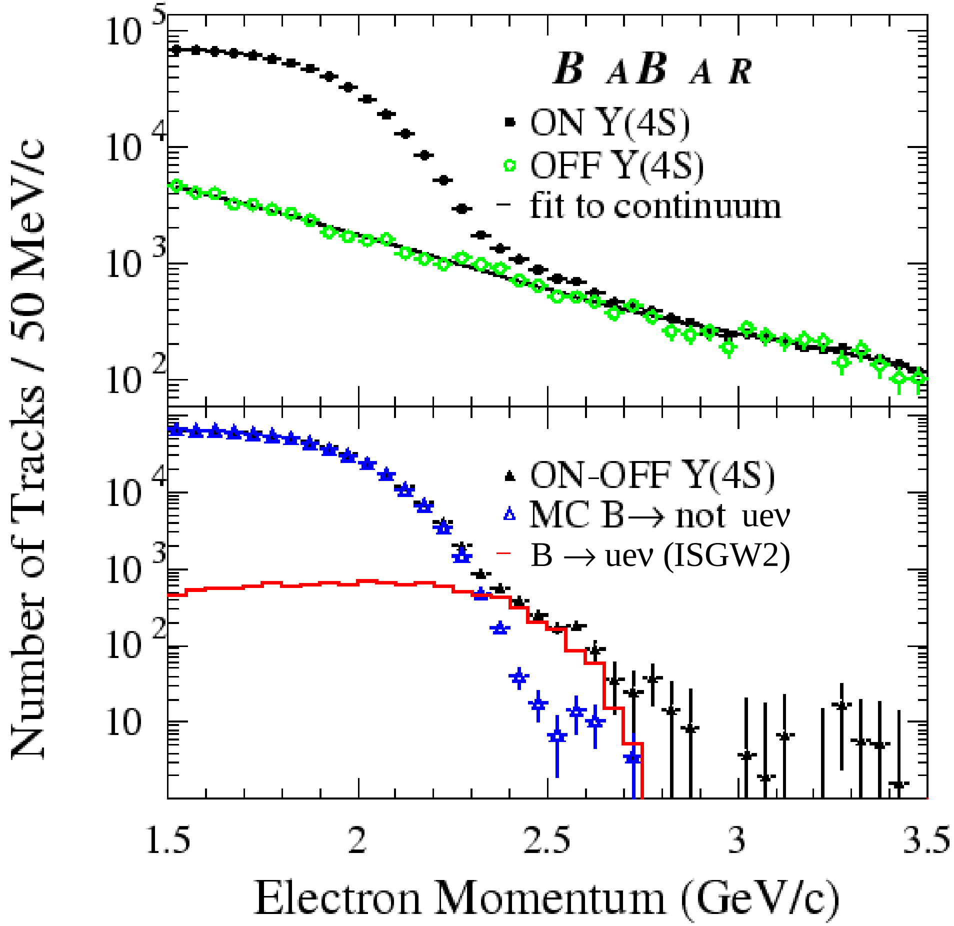
L_{off} = 8.7 fb^{-1}

$N_{B\bar{B}}$ = 55.2 x 10^{6}

Inclusive Analysis-Strategy $b \to u\, e\, \nu$

preliminary

- Measure $b \to u\, e\, \nu$ rate in electron energy range 2.3 ... 2.6 GeV
- Estimate continuum background using 4th degree Chebyshev-polynomial fit to off-peak data
- Other backgrounds from MC:
  - $B \to X_c\, e\, \nu$
  - $J/\Psi \to e^+ e^-$
  - $B \to X_c \to e$
  - mis-id hadrons from $B \to X_c$
- Correct for final-state radiation and bremsstrahlung



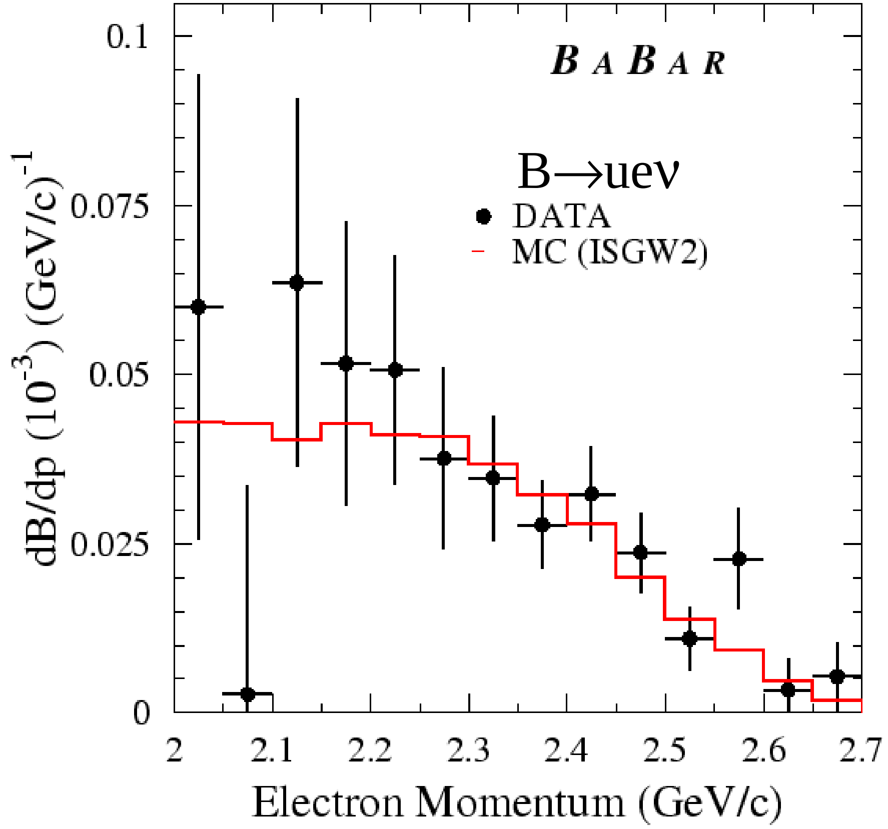
$$\Delta B = \frac{N_{on} - N_{off} - N_{B \nrightarrow u e \nu}}{2\, \epsilon\, N_{B\bar{B}}} \cdot (1 + \delta_{rad}) = (0.152 \pm 0.014 \pm 0.014) \times 10^{-3}$$

stat syst

Inclusive Estimation of $|V_{ub}|$

preliminary

- **Systematic errors on partial rate:**
  - Detector simulation 5%
  - Continuum subtraction 5%
  - MC $b \to c$ subtraction 3%
  - Momentum spectrum of B mesons 5%



- **Extrapolation to full rate:**
  - using input from CLEO's $b \to s\gamma$ measurement ($f_u = 0.074 \pm 0.014 \pm 0.009$, fraction of events in $2.3 < E_e < 2.6$ GeV):

$$B = (2.05 \pm 0.27_{exp} \pm 0.46_{fu}) \times 10^{-3}$$

$$|V_{ub}| = (4.43 \pm 0.29_{exp} \pm 0.25_{OPE} \pm 0.50_{fu} \pm 0.35_{s\gamma}) \times 10^{-3}$$

The Exclusive Analysis-Strategy $B \to \rho\, e\, \nu$

- **Study 5 modes $B \to H_u\, e\, \nu$, where $H_u = \rho^0, \rho^\pm, \omega, \pi^0, \pi^\pm$,**
  in 2 lepton-energy ranges:

  LOLEP : 2.0 < $E_{electron}$ < 2.3 GeV (large $b \to c\, e\, \nu$ backgrounds)

  HILEP : 2.3 < $E_{electron}$ < 2.7 GeV (large continuum backgrounds)

- **Binned Likelihood-Fit with 2 fit variables:**
  $\Delta E = E_{had} + E_{lept} + |p_\nu| - E_{beam}$, where $|p_\nu| \approx |p_{miss}|$, and $M_{had} = \pi\pi(\pi)$ mass

- **Take signal and background shapes from Monte Carlo simulations, and continuum shape from off-peak data**

- **Extrapolate partial branching fraction to entire lepton-energy spectrum using five different form-factor calculations.**

- **Determine $|V_{ub}|$ for each form-factor:**

$$|V_{ub}| = \sqrt{\frac{B(B^0 \to \rho^+ e^- \nu)}{\Gamma_{theo}\, \tau_{B^0}}}$$

Fitting for the $B \to \rho e \nu$ Branching Fraction

- **Extended binned maximum likelihood fit**
  - **M_{had} vs ΔE (10x10 bins for ρ, 6x10 bins for ω, 10 bins for π)**
  - **simultaneously for $\rho^{\pm}$, ρ^{0}, ω, $\pi^{\pm}$, π^{0}, and in 2 lepton energy regions**
  - **use method by Barlow/Beeston (Comp. Phys. Com 77, 219-228) to take finite MC statistics into account**
- **Make use of isospin and quark model relations:**
  - $\Gamma(B^0 \to \rho^- e^+ \nu) = 2\,\Gamma(B^+ \to \rho^0 e^+ \nu)$
  - $\Gamma(B^0 \to \pi^- e^+ \nu) = 2\,\Gamma(B^+ \to \pi^0 e^+ \nu)$
  - $\Gamma(B^+ \to \rho^0 e^+ \nu) = \Gamma(B^+ \to \omega e^+ \nu)$
- **9 parameter fit:**
  - **Par 1:** $\mathcal{B}(B \to \rho / \omega\, e \nu)$
  - **Par 2:** $\mathcal{B}(B \to \pi^0 / \pi^{\pm} e \nu)$
  - **Par 3+4: $b \to u$ downfeed (normalization in hilep/lolep)**
  - **Par 5..9: $b \to c$ (normalization)**

Fit Projections for $B^0 \to \rho^- e^+ \nu$

- direct signal
- crossfeed signal
- other $b \to u e \nu$
- $b \to c e \nu$

(isospin-constrained average of $\rho^\pm$ and ρ^0)

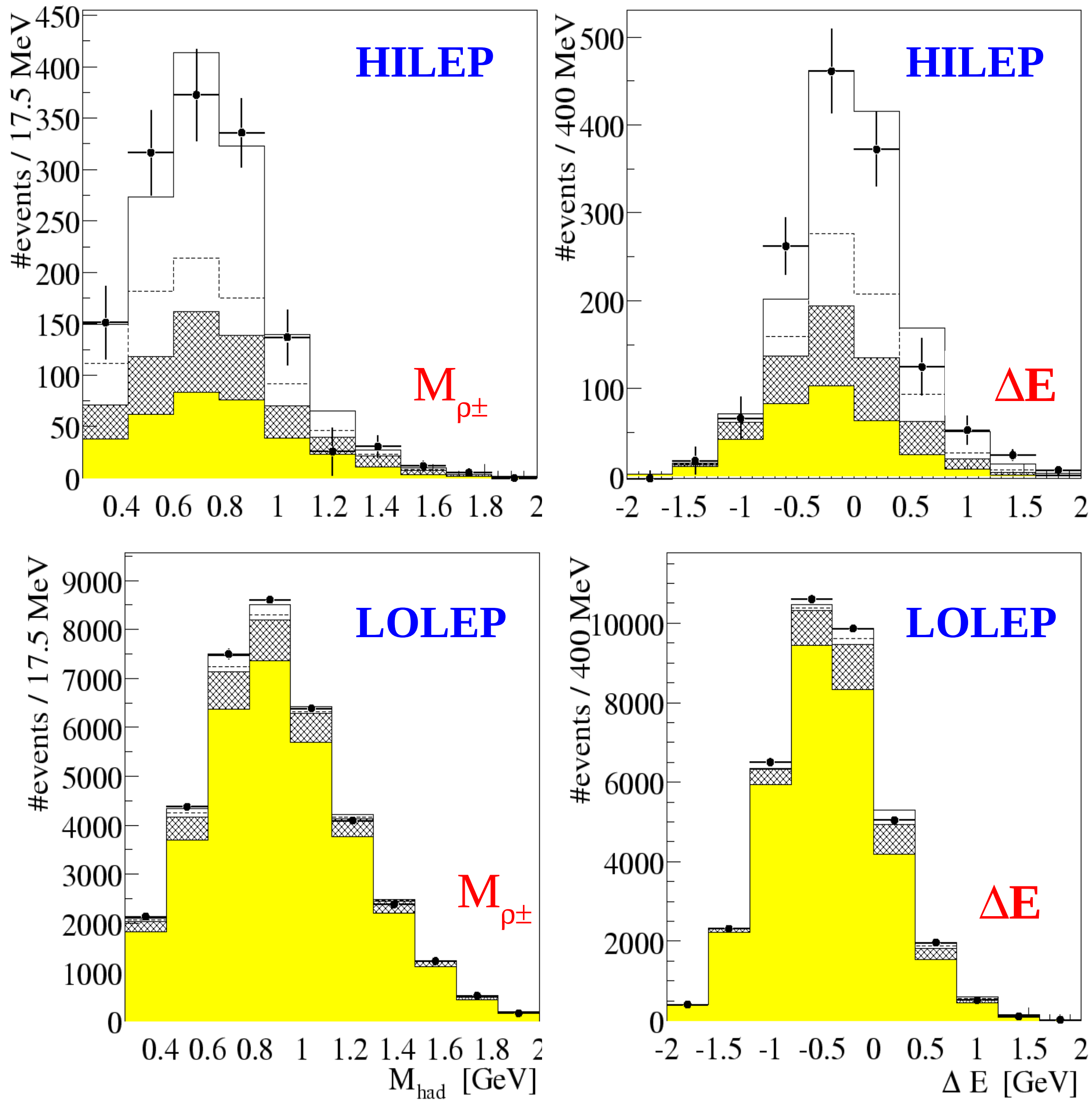
χ^2= 91(93 Ndof), P=52%

Direct signal yields

HILEP (2.3 - 2.7 GeV):

510 ± 62 $B^0 \to \rho^- e^+ \nu$ +CC

324 ± 40 $B^+ \to \rho^0 e^+ \nu$ +CC



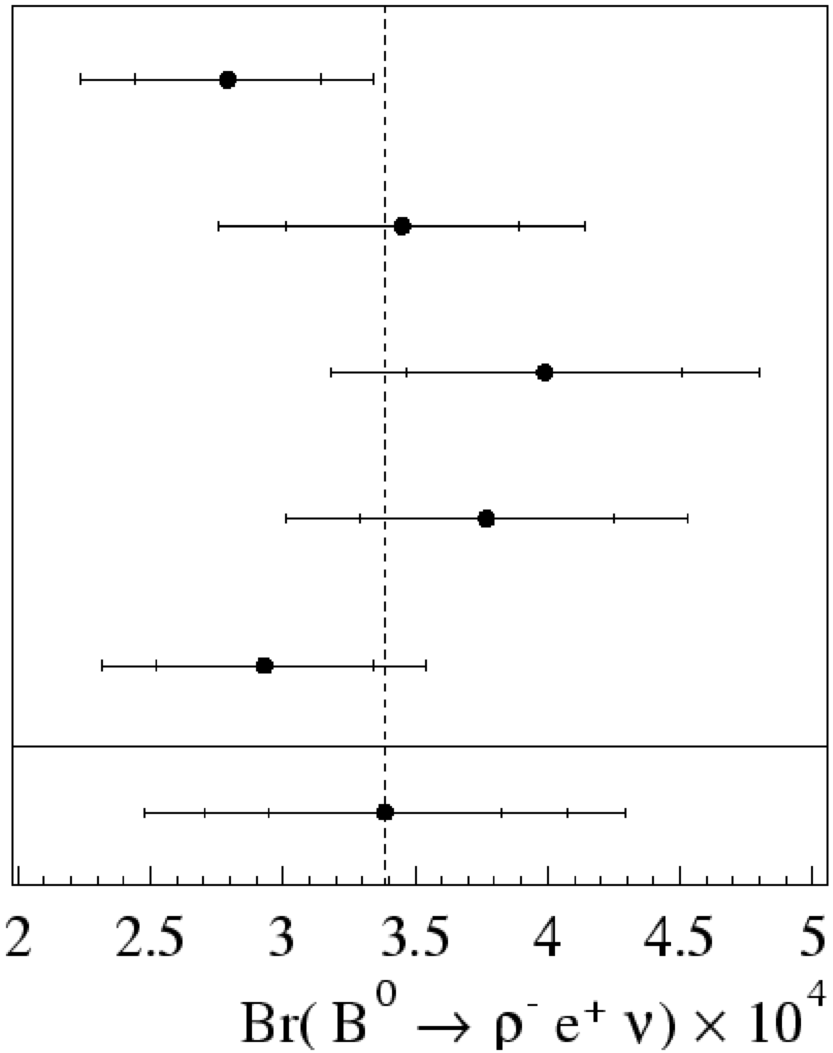
Summary of Systematic Errors on Br($B \rightarrow \rho e \nu$)

track efficiency	±5 %	Detector Simulation ± 8 %
track resolution / track smearing	±1 %	
photon/pi0 efficiency	±5 %	
photon/pi0 energy scale	±3 %	
electron id	±2 %	
fake lepton rate (electrons)	±1 %	
resonant $b \rightarrow u$ downfeed composition (ISGW2)	+6,-4 %	Background Modeling +11 , -10 %
non-resonant $b \rightarrow u$ downfeed (Neubert & Fazio)	±9 %	
$b \rightarrow c$ composition	+1.4,-1.7 %	
B counting	±1.6 %	Others ± 9 %
B lifetime	±1.5 %	
f_{+-}/f_{00}	±1 %	
isospin breaking	±0 %	
fit method	+4 , -6 %	
data selection	±6 %	

TOTAL: ±15.5 %

$B^0 \to \rho^- e^+ \nu$ Branching Fraction Results

preliminary



ISGW2:
$2.79 \pm 0.35 \pm 0.43$

UKQCD:
$3.45 \pm 0.44 \pm 0.53$

LCSR:
$3.99 \pm 0.52 \pm 0.62$

Beyer/Melikhov:
$3.77 \pm 0.48 \pm 0.58$

Ligeti/Wise:
$2.93 \pm 0.41 \pm 0.45$

Theoretical error on the combined result:

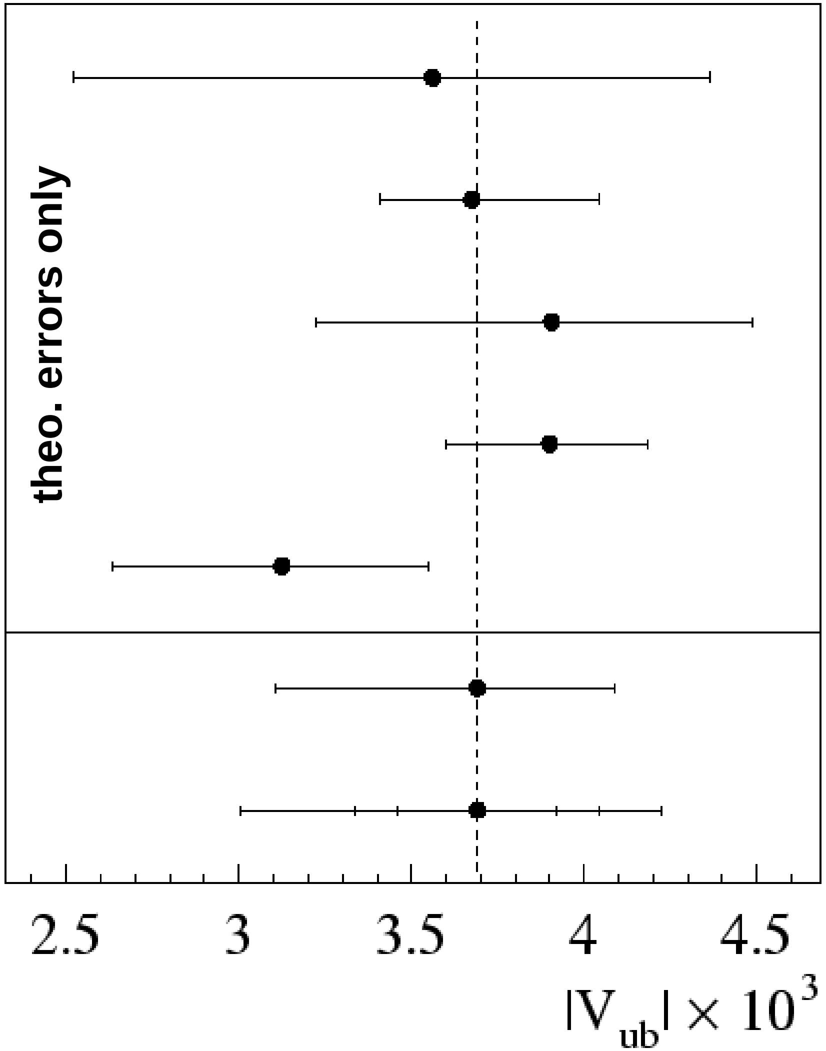
Half of the full spread seen between the different form-factors.

Combined Result:

$$(3.39 \pm 0.44 \pm 0.52 \pm 0.60) \times 10^{-4}$$

Exclusive $|V_{ub}|$ Results

preliminary



ISGW2:
$3.56 \pm 0.22 \pm 0.27 \;^{+0.80}_{-1.04}$

UKQCD:
$3.68 \pm 0.23 \pm 0.27 \;^{+0.37}_{-0.27}$

LCSR:
$3.91 \pm 0.25 \pm 0.29 \;^{+0.58}_{-0.68}$

Beyer/Melikhov:
$3.90 \pm 0.24 \pm 0.29 \;^{+0.28}_{-0.30}$

Ligeti/Wise:
$3.12 \pm 0.21 \pm 0.23 \;^{+0.42}_{-0.49}$

Combined

$$|V_{ub}| = \sqrt{\frac{B(B^0 \to \rho^+ e^- \nu)}{\Gamma_{theo}\,\tau_{B^0}}}$$

Quoted errors on Γ_{theo} vary from 15% to 50%.

Combined result:
weighted average of 5 form-factor results

Theoretical error on the combined result:
Half of the full spread seen between the FFs (including theoretical errors)

Combined Result:

$$|V_{ub}| = (3.69 \pm 0.23 \pm 0.27 \;^{+0.40}_{-0.59}) \times 10^{-3}$$

Conclusions & Outlook

BABAR **measurements of the inclusive $b \to u\, e\, \nu$ rate and the branching fraction $B \to \rho\, e\, \nu$ were presented. The matrix element $|V_{ub}|$ can be derived from both measurements.**

There is room for improvement in the future, both on the experimental and theoretical side, e.g.:

Inclusive Analysis:

- **Perform *BABAR* combined measurement of $b \to u\, l\, \nu$ and $b \to s\gamma$.**
- **Make use of fully reconstructed B-Mesons on the tagging side.**

Exclusive Analysis:

- **Gain better understanding of the downfeed background.**
- **Improve neutrino momentum resolution, include larger fraction of the electron energy spectrum**
- **Hope for progress in form-factor lattice-QCD calculations**

Inclusive Event Selection

Backup Slide

- require more than 3 tracks
- 2nd normalized Fox Wolfram Moment $R_2 < 0.4$
- CMS missing momentum > 1 GeV/c
- $-0.9 < \cos\theta_{miss} < 0.8$, where θ = polar angle of missing momentum
- $\cos\theta_{l\text{-}miss} < 0$, where $\theta_{l\text{-}miss}$ = angle between electron and missing momentum
- Electron Selection:
  - select electron of highest momentum
  - cut based selector using information from drift chamber, calorimeter and chrenkov detector.
  - determine efficiency and fake rate from pure data control samples
  - veto electrons from J/Ψ–mesons: $M_{ee} < 3.05$ or $M_{ee} > 3.15$

- **Selection Efficiency for $2.3 < p_{CMS} < 2.6$ GeV : 27.7 %**

Comparison with Other Measurements *Backup Slide*

Inclusive Results:

Experiment	$\|V_{ub}\| \times 10^3$	$b \to u$ rate x 10^3
BABAR	$4.43 \pm 0.29 \pm 0.25 \pm 0.50 \pm 0.35$ Stat. Syst. / OPE, b-mass / f_u / $s\gamma$	$2.05 \pm 0.27 \pm 0.46$ Stat. Syst. / f_u
CLEO	$4.08 \pm 0.34 \pm 0.44 \pm 0.28$ Stat. Syst. / OPE, b-mass / f_u	$1.77 \pm 0.29 \pm 0.38$ Stat. Syst. / f_u
LEP average	$4.09^{+0.36}_{-0.39}\,^{+0.42}_{-0.47}\,^{+0.24}_{-0.26} \pm 0.21$ Stat. Syst. / $b \to c$ / $b \to u$ / HQE	$1.71 \pm 0.31 \pm 0.37 \pm 0.21$ Stat. Syst. / $b \to c$ / $b \to u$

Exclusive Event Selection I

Backup Slide

- **Multihadron selection**
  - **Normalized Fox Wolfram Moment R_2<0.9**
  - **N_{tracks} >4 || (N_{tracks}>3 && $N_{clusters}$>5)**
- **Electron ID**
  - **likelihood based electron selector using information from calorimeter, driftchamber, and cherenkov detector.**
  - **input: well reconstructed tracks whithin calorimeter acceptance**
- **Suppression of other backgrounds**
  - **lepton must not be compatible with a J/ψ decay:**

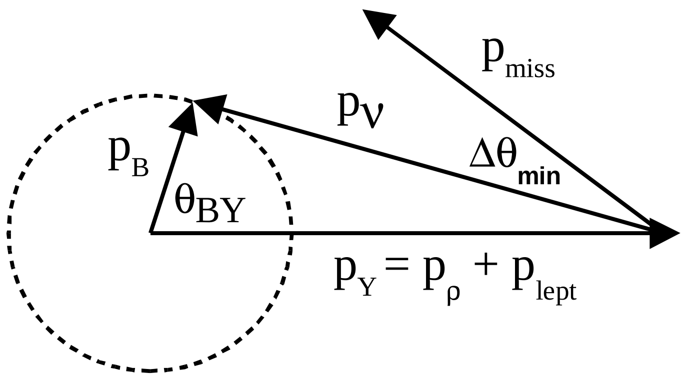
    3 < $M_{J/\Psi}$ < 3.14 GeV

    MC: Rejects 76% of all selected electrons from true J/Ψs.
  - **electrons must not be compatible with a photon conversion.**
    MC: Rejects 38% of all selected electrons from true conversions.

Exclusive Event Selection II

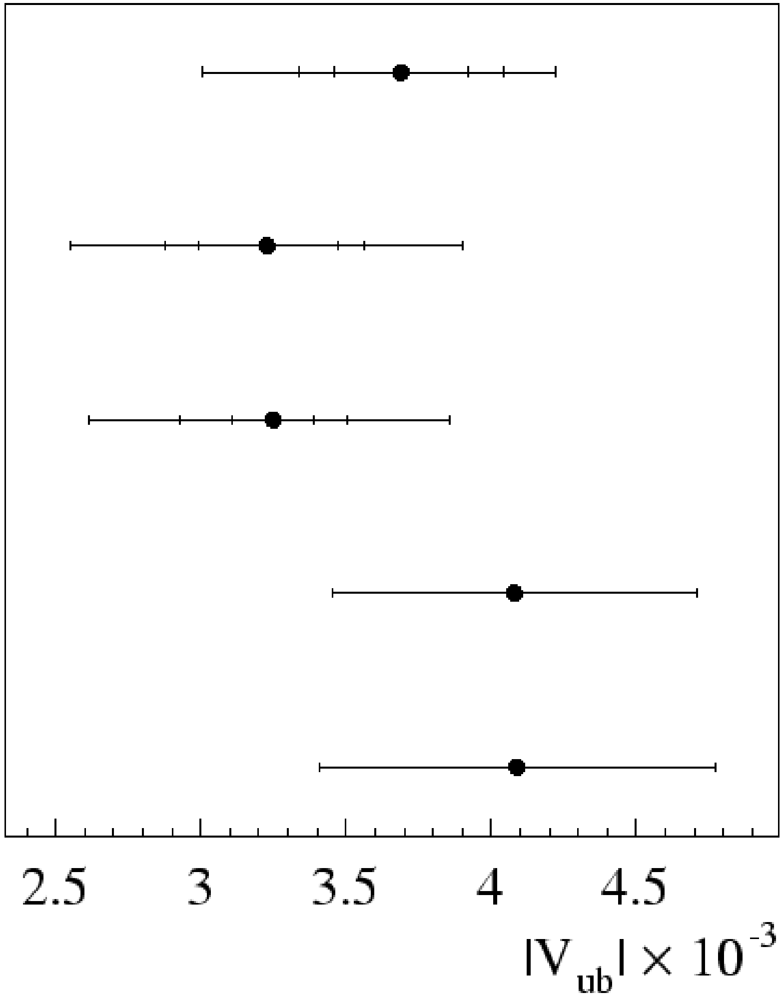
Backup Slide

- **Hadron reconstruction**
  - **Input: well reconstructed tracks**
  - **reject track identified as kaon**
  - **π^0 candidates: $120 < m_{\pi 0} < 145$ MeV**
  - **$\max(p_{\pi 1}, p_{\pi 2}) > 400$ MeV, other $p_\pi > 200$ MeV**
- **Consistency requirement**
  - **$|\cos\theta_{BY}| < 1.1$, rejects 60% of bad combinations without loosing signal**
  - **$\cos\Delta\theta_{min} > 0.8$**
- **Continuum suppression**
  - **$R_2 < 0.4$ (R_2 with tracks and clusters)**
  - **$|\cos(\theta_{miss})| < 0.9$**
  - **neural network with 14 input variables**



$$\cos\Theta_{BY} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2|p_B| \cdot |p_Y|}$$

Comparison with Other Measurements *Backup Slide*



BABAR exclusive:
$3.69 \pm 0.23 \pm 0.27 \, ^{+0.40}_{-0.59}$
preliminary

CLEO exclusive I
$3.23 \pm 0.24 \, ^{+0.23}_{-0.26} \pm 0.58$

Similar analysis strategy, sensitive to ρ channels

CLEO exclusive II
$3.25 \pm 0.14 \, ^{+0.21}_{-0.29} \pm 0.55$

average of 2 CLEO measurements

CLEO inclusive:
4.08 ± 0.63 (stat+syst+theo)

LEP inclusive:
4.09 ± 0.68 (stat+syst+theo)

Form Factor Models Overview

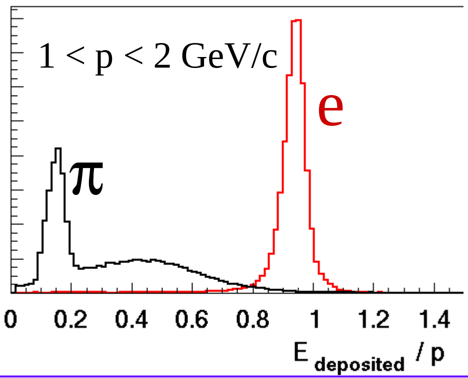
Backup Slide

ISGW2	Isgur, Scora, Grinstein, Wise normalized at $q^2=q^2_{max}$	constituent quark model
UKQCD	UKQCD group 24^3x48 lattice, quenched calculations at $q^2=q^2_{max}$ use of HQS and LCSRs to cover entire q^2 range	lattice QCD calculation
LCSR	Ball, Braun normalized at small q^2, complementary to UKQCD, use of LCSRs	light cone sum rules
B/M	Beyer, Melikhov fully relativistic UKQCD results used for normalization at q^2_{max}	constituent quark model
L/W	Ligeti, Wise relates semileptonic B and D decays uses input for $D \rightarrow K^* l \nu$ from E791 measuerements	SU(3) flavour symmetry, SU(4) HQ spin-falvour symmetry

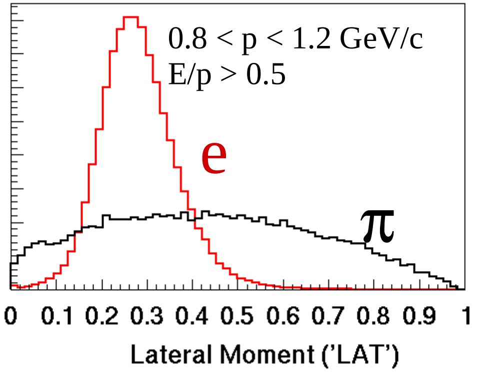
The BABAR Detector

Backup Slide

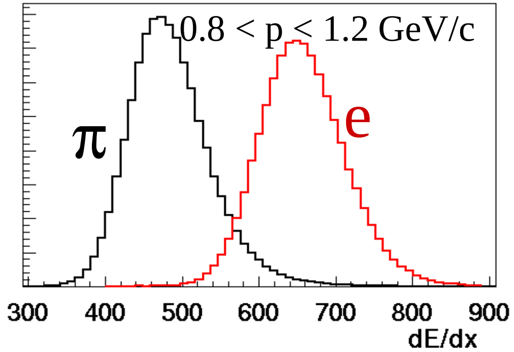
E/p E.M. calorimeter



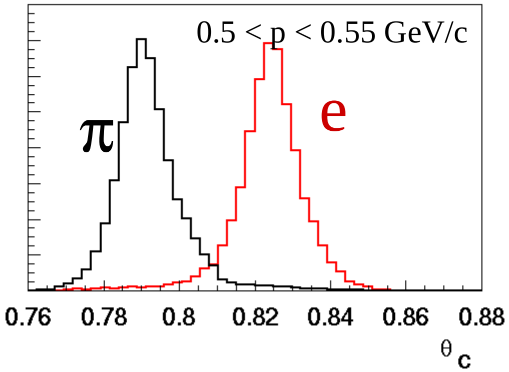
shower shape

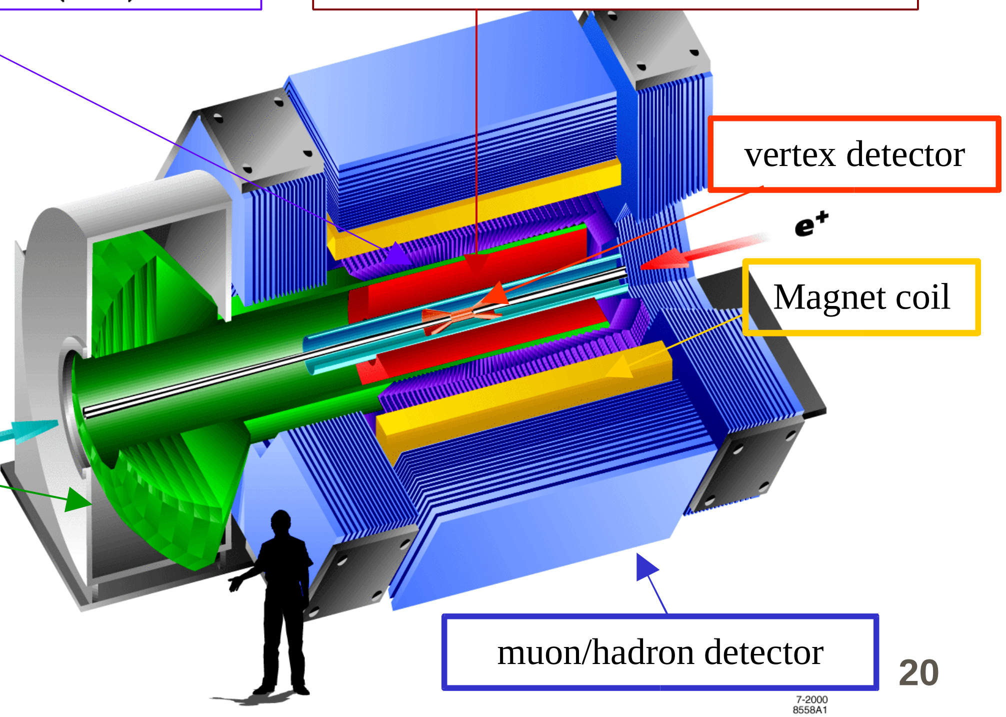


DE/dx driftchamber



θ_c *Cherenkov detector*





Electron Identification