Inclusive Electron Spectrum from Semileptonic B Decays and Determination of $|V_{ub}|$

preliminary results from BABAR

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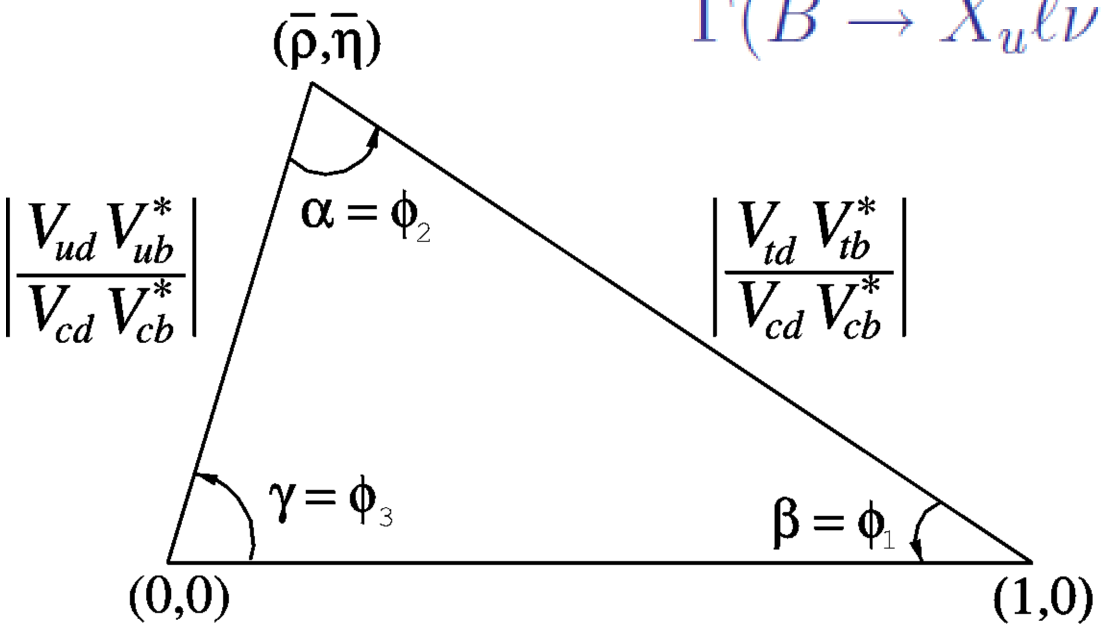
$B \to X_u \ell\nu$ Decays and Unitarity Triangle

$B \to X_u \ell\nu$ decays are the best way to measure $|V_{ub}|$



$$\Gamma(B \to X_u \ell\nu) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3} F^2$$

$$|V_{ub}| \simeq 10^{-3}$$

F - form factor

Methods to Extract $B \rightarrow X_u l\nu$ Decays

• <u>tagged analysis</u>

full reconstruction B_{tag} decay

provides kinematics of signal decay

neutrino reconstruction, M_X, q^2

$M_X < M_D$ eliminates the charm background and accepts 80% of $B \rightarrow X_u \ell\nu$

$q^2 > (M_B - M_D)^2$ eliminates the charm background and accepts 20% of $B \rightarrow X_u \ell\nu$

reduces the statistics considerably

• <u>untagged analysis</u>

measurement of inclusive lepton spectrum of semileptonic charmless decays

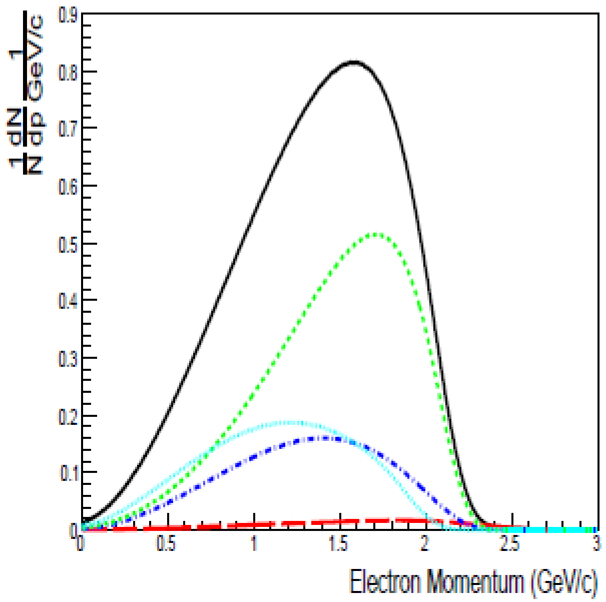
in B rest frame the endpoint of spectrum for the signal is ~ 2.6GeV/c and for $B \rightarrow X_c \ell\nu$ ~2.3GeV/c

$B \rightarrow De\nu$ $B \rightarrow D^* e\nu$

$B \rightarrow D^{**} e\nu + B \rightarrow D^{(*)}\pi e\nu$

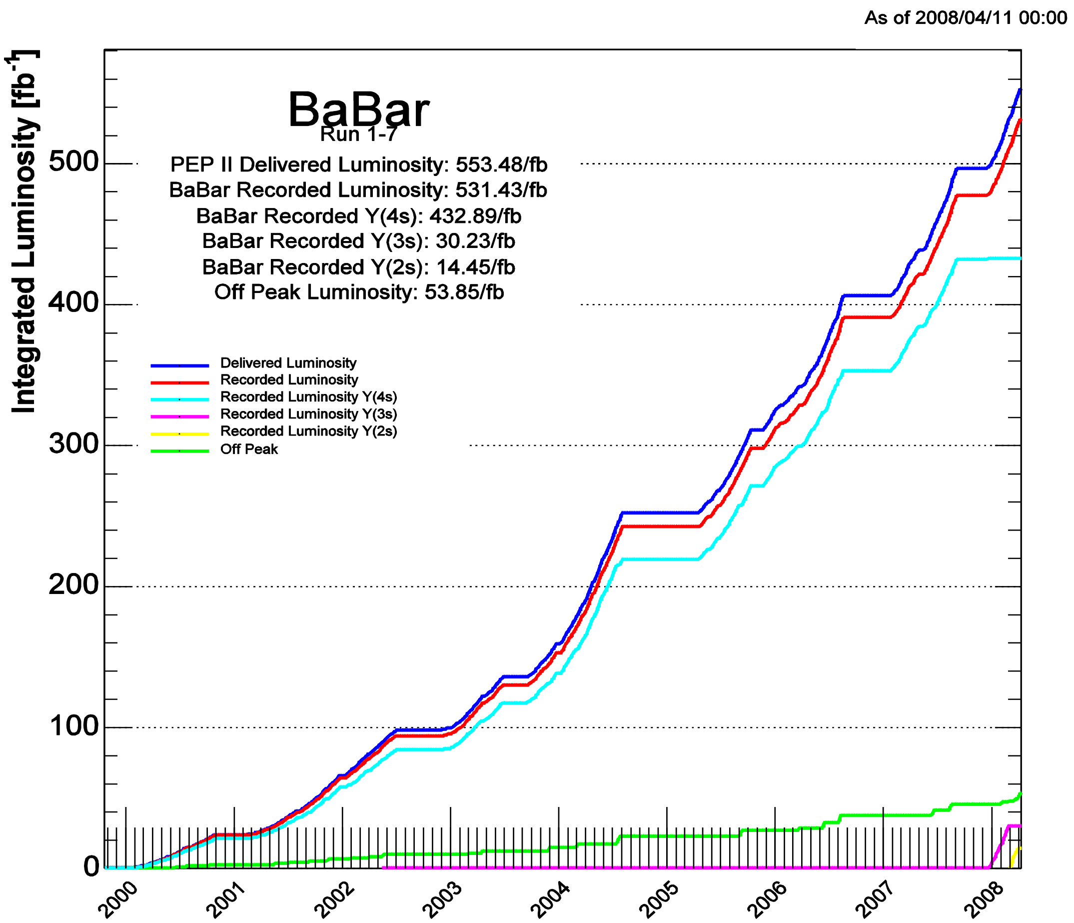
$B \rightarrow X_u e\nu$ $B \rightarrow X e\nu$

$B \rightarrow X_u \ell\nu$ are to 50 times less than $B \rightarrow X_c \ell\nu$



Data Sample

- the data sample - 466.5 million BBbar events corresponding to an integrated luminosity of 424.9 fb^{-1} recoded at the ϒ(4S)
- the data sample of 44.4 fb^{-1} recorded below the ϒ(4S) used as non-BBbar sample
- MC sample - 1450.7 million BBbar events



Event Selection

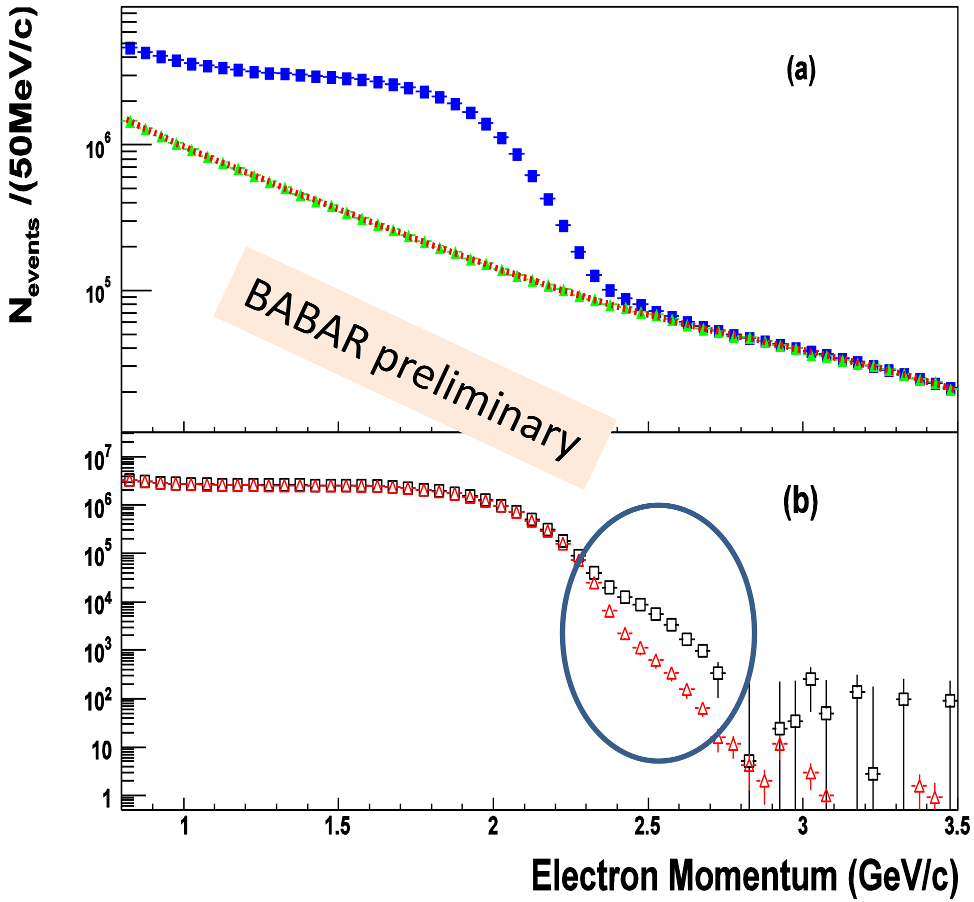
- at least one electron with momentum $0.8 < p_{cms} < 5.0$GeV/c.
- $-0.71 < \cos\theta_e < 0.90$
  $\cos\theta_e$ - the cosine of the angle between the electron momentum and beam direction (lab)
- the number of charged tracks greater than 3

- reject electrons from the decay $J/\psi \rightarrow e^+e^-$
  reject event if there is combination with invariant mass in the interval $3.00 < m_{e+e-} < 3.15$GeV/c^2

To suppress non-BBbar events neural net with the following input variables is used:

- R_2 - the ratio of the second to the zeroth Fox-Wolfram moments (cms)
- $l_2 = \Sigma\, p_i \cos^2\theta_i / 2E_{beam}$ - charged and neutral tracks without electron, where all angles are measured with respect to the electron axis (cms)
- $\cos\theta_{e-roe}$ - the cosine of angle between the electron momentum and the thrust axis of the rest of event

Electron Spectrum



(a) - on-resonance (solid squares)

off-resonance (solid triangles)

dotted line - the fit to non-BBbar

(b) - ON − OFF (open squares)

BBbar MC (B→ Xuev excluded) (open triangles)

Fit to non-BBbar and BBbar Backgrounds

binned χ^2 fit

N_j – ϒ(4S) sample n_i – non-BBbar sample

$$\chi^2 = \sum_{i,j}(f(\vec{a},p_i) + S(\vec{b},\vec{t},p_i) - N_i)V_{ij}^{-1}(f(\vec{a},p_j) + S(\vec{b},\vec{t},p_j) - N_j) + \sum_i \frac{(f(\vec{a},p_i) - r_L n_i)^2}{r_L^2 n_i} + \sum_k \frac{(b_k - b_k^{(0)})^2}{\sigma_{b_k}^2} + \frac{(r_L - r_L^{(0)})^2}{\sigma_{r_L}^2}$$

$$V_{ij} = (N_i + \sigma^2_{(MC)\,i})\delta_{ij} + V_{ij}^{PID} \qquad S(\vec{b},\vec{t},p) = \sum_k b_k g_k(\vec{t},p_i)$$

b_k - the correction factors to the MC default branching fractions

$g_k(t_i,p_j)$ – MC predictions for BBbar background and signal

t_i - ρ^2, R_1, R_2, and ρ_{2D} (parameters of form factors are fixed)

$$f(\vec{a},p) = a_0(exp(a_1 p + a_2 p^2 + a_3 p^3) + exp(a_4 p + a_5 p^2))$$

a_i - the set of free parameters function of the fit non-BBbar background

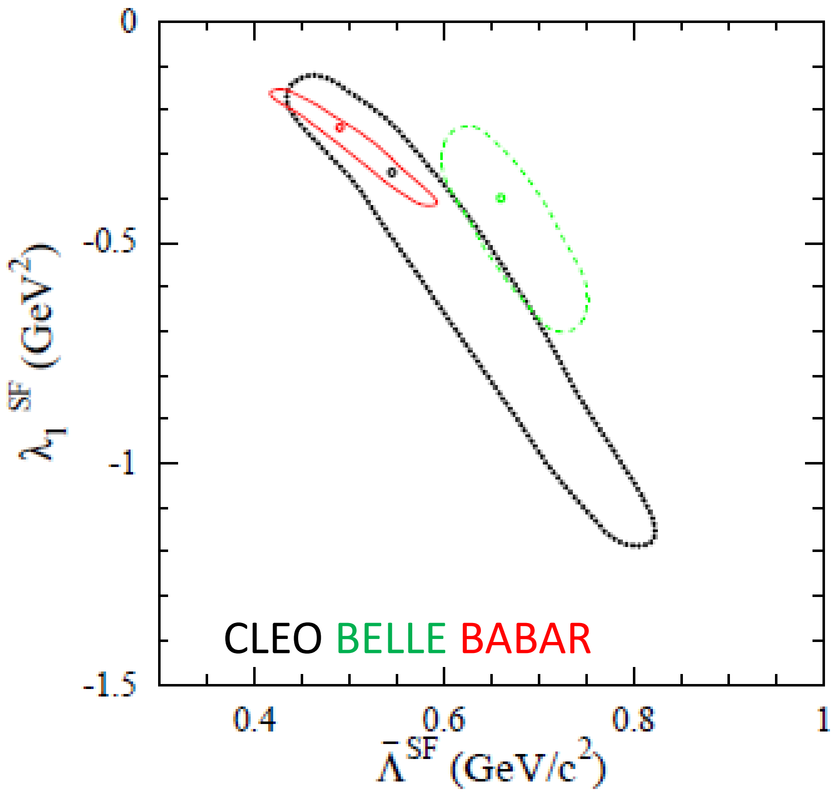
$$r_L^{(0)} = \frac{s_{OFF}}{s_{ON}} \frac{\int L_{ON}\, dt}{\int L_{OFF}\, dt} = 9.560 \pm 0.003 \pm 0.006$$ ratio OFF/ON luminosities

Theoretical Calculations of $B \rightarrow X_u l\nu$ Decays

DF

F. DeFazio, and M. Neubert, JHEP 9906, 017 (1999)

- based on differential decay rate with the $O(\alpha_s)$ corrections to leading order in the heavy-quark expansion
- simple convolution of parton model spectrum with function, which takes into account momentum distribution of the heavy quark inside the B-meson



$$\bar{\Lambda}^{SF} = M_B - m_b$$

BABAR $\bar{\Lambda}^{SF} = 0.49^{+0.10}_{-0.06}$ $\lambda_1 = -0.24^{+0.09}_{-0.18}$

Theoretical Calculations of $B \rightarrow X_u l\nu$ Decays

more comprehensive calculations

- BLNP

S.W. Bosch, B. O. Lange, M. Neubert, and G. Paz, Nucl. 894 Phys. B 699, 335 (2004)

- GGOU

P. Gambino, P. Giordano, G. Ossola, N. Uraltsev, JHEP 908 10, 058 (2007)

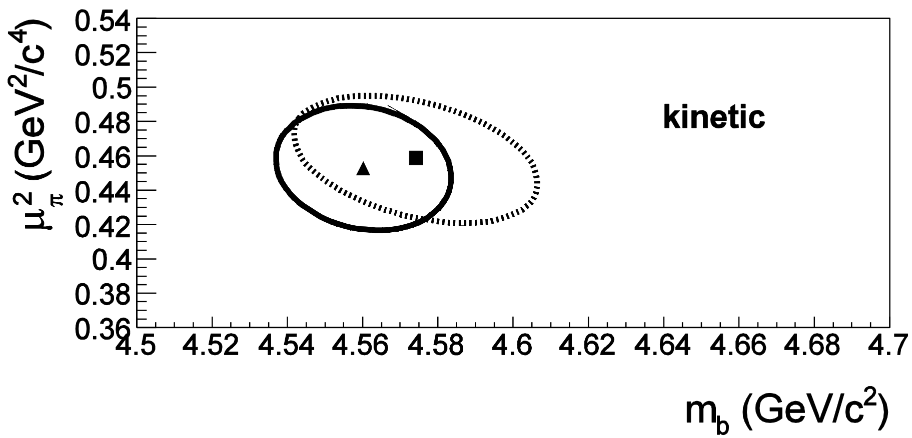
these calculations include perturbative and non- perturbative effects by using an expansion in powers of $1/m_b$ and non-perturbative functions which depend of a set of parameters

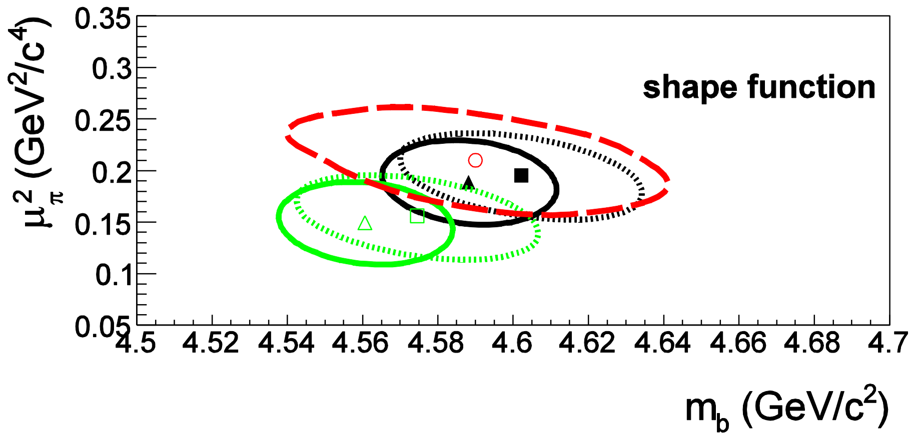
- DGE

J. R. Andersen, E. Gardi, JHEP 0601, 097 (2006)

based on a calculation of non-perturbative functions using Sudakov resummation given in the dressed gluon exponentiation

GGOU and BLNP Parameters m_b and μ_π^2





m_b and μ_π^2 results from HFAG 2012

solid line: $B \to X_c l\nu$ moments with m_c constraint

dotted line: $B \to X_c l\nu$ and $B \to X_s \gamma$ moments

<u>kinetic</u>

m_b=4.560±0.23GeV

μ_π^2=0.453±0.036GeV^2

<u>shape function</u>

μ=1.5GeV default until 2010

μ=2.0GeV suggested in 2010

m_b=4.561±0.23GeV

μ_π^2=0.149±0.040GeV^2

Our previous analysis: BaBar, Phys.Rev. D73(2006)012006 (p_e>2GeV/c)

Fit to Inclusive Spectra

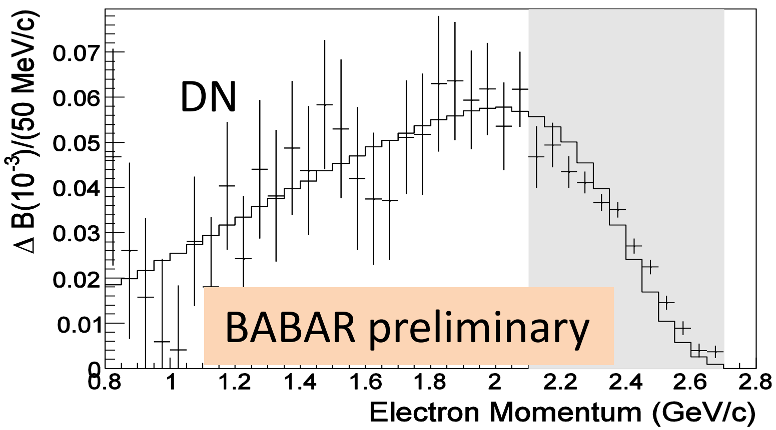
BABAR preliminary

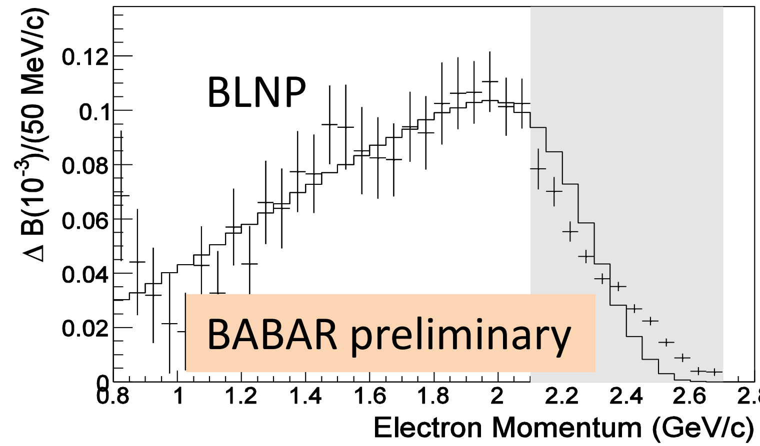
	DN	BLNP	GGOU	DGE
$De\nu$	2.311 ± 0.095	2.286 ± 0.095	2.306 ± 0.095	2.308 ± 0.096
$D^*e\nu$	5.838 ± 0.059	5.630 ± 0.061	5.802 ± 0.059	5.836 ± 0.059
$D^{(*)}\pi e\nu$	< 0.099	< 0.034	< 0.087	< 0.078
$D^{**}e\nu$	2.348 ± 0.096	2.621 ± 0.102	2.398 ± 0.099	2.351 ± 0.096
$D'^{(*)}e\nu$	0.054 ± 0.015	0.028 ± 0.015	0.049 ± 0.015	0.053 ± 0.014
$X_u e\nu$	0.154 ± 0.006	0.249 ± 0.010	0.171 ± 0.007	0.158 ± 0.006
$D \to e$	0.981 ± 0.007	0.967 ± 0.007	0.979 ± 0.007	0.981 ± 0.007
$r_L/r_L^{(0)}$	1.0002 ± 0.0007	1.0002 ± 0.0007	1.0002 ± 0.0007	1.0002 ± 0.0007
$Xe\nu$	10.70 ± 0.05	10.81 ± 0.05	10.73 ± 0.05	10.71 ± 0.05
$\chi^2/ndof$	$93.3/85$	$98.6/85$	$94.0/85$	$92.7/85$

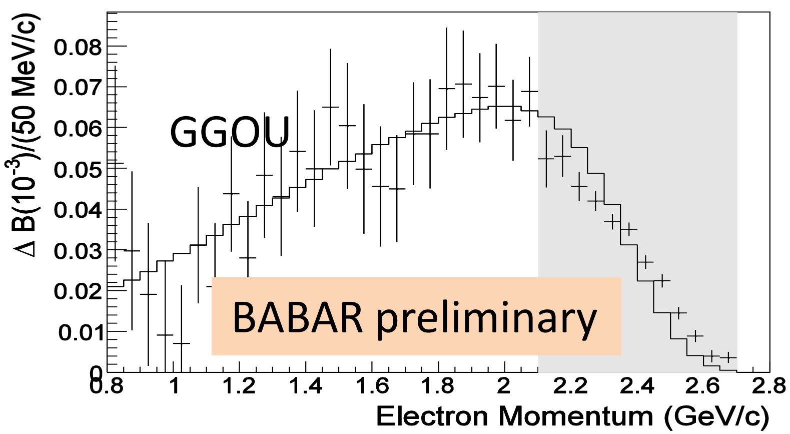
branching fractions (%) and D→e (scale factor)

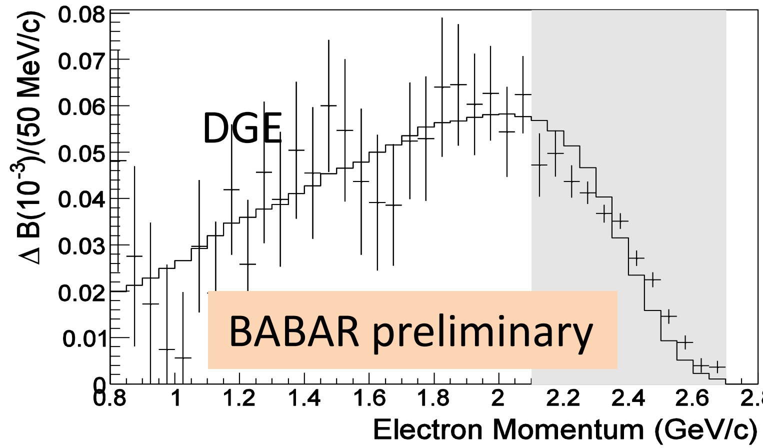
only the measurements for branching ratio of B → Dev and r_L are constrained to within their uncertainties in χ^2

The Differential Branching Fraction of $B \to X_u e\nu$ ($\Upsilon(4S)$ rest frame)



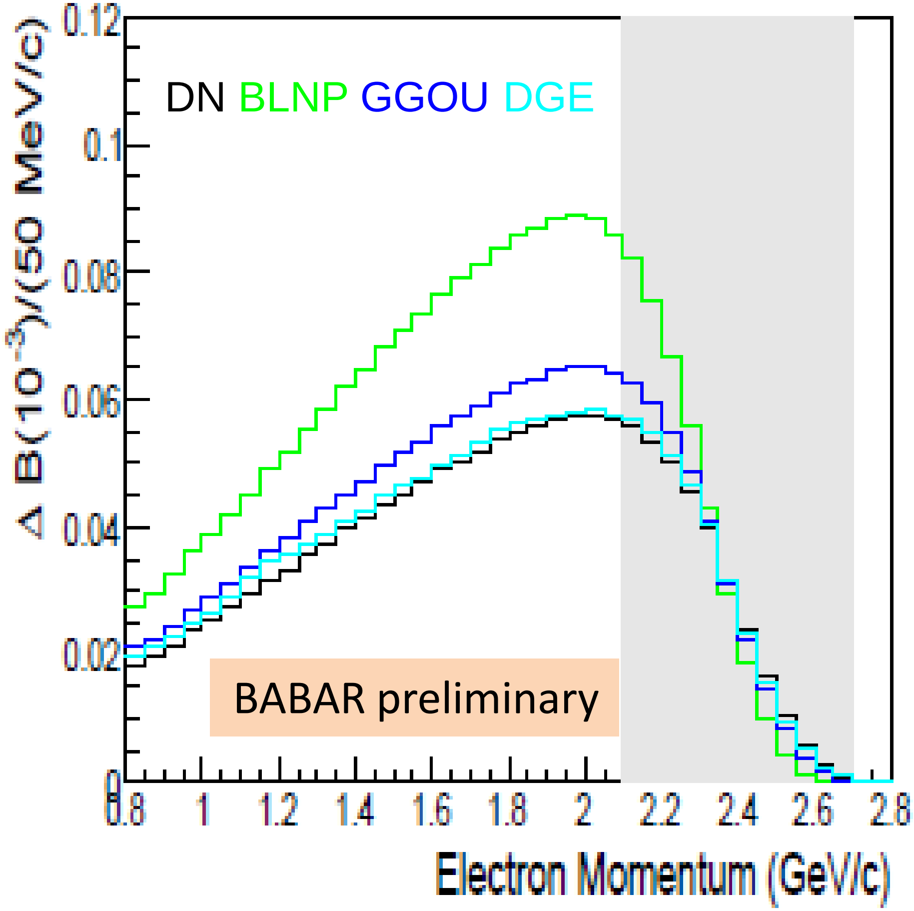






shaded area is the wide bin in the fit to reduce the sensitivity to the shape of the signal spectrum in endpoint region, error bars include statistical uncertainty only

The Differential Branching Fraction of $B \to X_u e\nu$ ($\Upsilon(4S)$ rest frame)

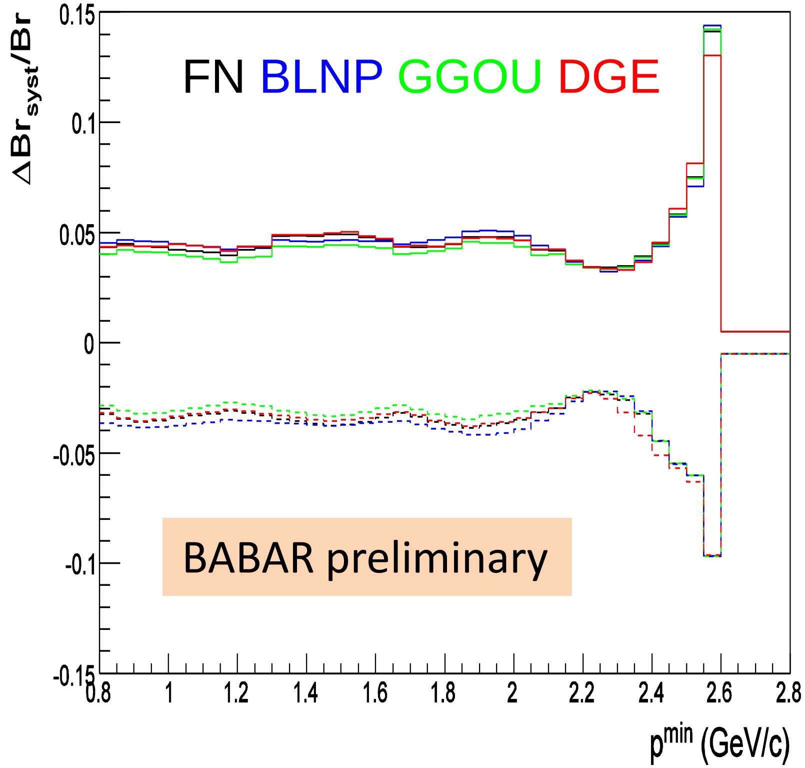


the results depend on the predicted shape of lepton spectrum for $B \to X_u e\nu$ decays

the experimental sensitivity is mostly determined from the electron spectrum above 2.1 GeV/c

MC spectra with normalization based on the fit

Assessment of Experimental Systematic Uncertainties



ΔB_{syst} - systematic uncertainty for branching fraction in range p^{min}-2.6GeV/c

List of effects evaluated to determine the systematic uncertainties:

luminosity, cuts on number of charged, photon energy, neural net output and efficiency of charged

form factors of D, D^*, D^{**}

branching ratios of D^{**} modes

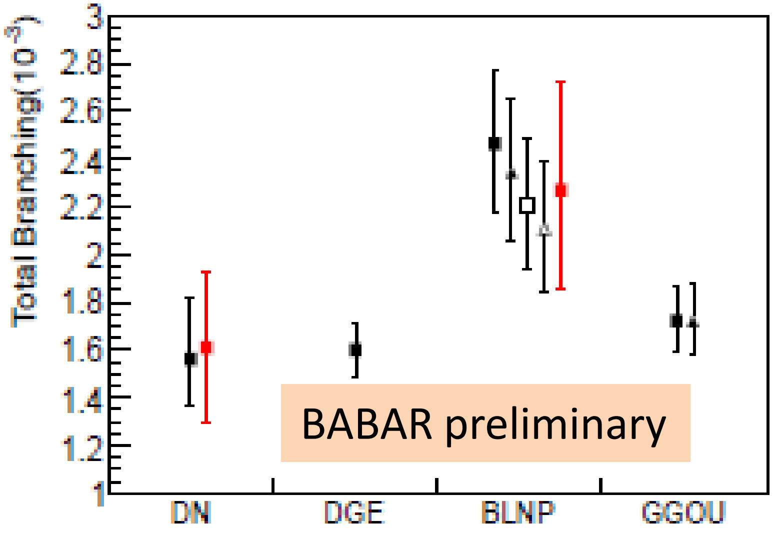
$Br(B \to D'e\nu)/Br(B \to D^{*\prime}e\nu)$
And widths of $D^{(*)\prime}$

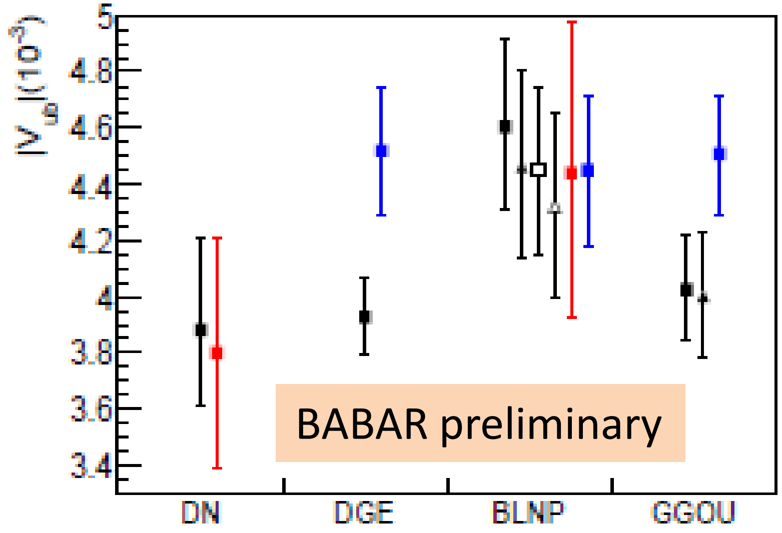
J/ψ, π, K, p, τ backgrounds

bremsstrahlung, beam energy, wide bin

non-BBbar background approximation

Summary





solid squares and triangles – X_c with mc constraint fit and X_c+$X_s\gamma$ fit of SF parameters (BLNP and GGOU)

solid and open - translation “kinetic” to “shape-function” with μ = 2.0GeV and μ = 1.5GeV (BLNP), respectively

results based on 0.8-2.6GeV/c momentum range

HFAG 2014 average based on tagged and untagged measurements

Consistent with and more precise than our previous result:

BaBar, Phys.Rev. D73(2006)012006 (p_e > 2 GeV/c)

Conclusion

We have measured

- inclusive electron spectra for $B \rightarrow Xe\nu$
- total branching fraction of $B \rightarrow X_u e\nu$ decays
- $|V_{ub}|$

- the results for the total branching fraction and V_{ub} depend on the predicted shape of lepton spectrum for $B \rightarrow X_u e\nu$ decays
- the experimental sensitivity is mostly determined from the electron spectrum above 2.1 GeV/c

- good agreement with HFAG 2014 for BLNP and some tension for GGOU and DGE

BACKUP

Results for Br(B → $X_u e\nu$) (the range pe=2.0-2.6GeV/c was used)

BABAR preliminary

$\mathcal{B} \times 10^3$	model
$1.703 \pm 0.124_{stat+syst}\ {}^{+0.259}_{-0.172}{}_{SF}\ {}^{+0.064}_{-0.053}{}_{theory}$	DN
$1.735 \pm 0.124_{stat+syst}\ {}^{+0.133}_{-0.126}{}_{theory}$	DGE
m_c constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$2.282 \pm 0.158_{stat+syst}\ {}^{+0.152}_{-0.136}{}_{SF}\ {}^{+0.254}_{-0.218}{}_{theory}$	BLNP
$1.843 \pm 0.127_{stat+syst}\ {}^{+0.092}_{-0.082}{}_{SF}\ {}^{+0.084}_{-0.148}{}_{theory}$	GGOU
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$2.188 \pm 0.152_{stat+syst}\ {}^{+0.172}_{-0.154}{}_{SF}\ {}^{+0.239}_{-0.206}{}_{theory}$	BLNP
$1.839 \pm 0.126_{stat+syst}\ {}^{+0.115}_{-0.099}{}_{SF}\ {}^{+0.178}_{-0.168}{}_{theory}$	GGOU
m_c constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$2.518 \pm 0.170_{stat+syst}\ {}^{+0.195}_{-0.166}{}_{SF}\ {}^{+0.273}_{-0.226}{}_{theory}$	BLNP
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$2.405 \pm 0.165_{stat+syst}\ {}^{+0.211}_{-0.179}{}_{SF}\ {}^{+0.254}_{-0.212}{}_{theory}$	BLNP

Results for Br(B → $X_u e\nu$) (the range pe=0.8-2.6GeV/c was used)

BABAR preliminary

$\mathcal{B} \times 10^3$	model
$1.562 \pm 0.091_{stat+syst}\ {}^{+0.240}_{-0.166}\,{}_{SF}\ {}^{+0.016}_{-0.014}\,{}_{theory}$	DN
$1.602 \pm 0.091_{stat+syst}\ {}^{+0.069}_{-0.064}\,{}_{theory}$	DGE
m_c constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$2.208 \pm 0.127_{stat+syst}\ {}^{+0.163}_{-0.146}\,{}_{SF}\ {}^{+0.179}_{-0.186}\,{}_{theory}$	BLNP
$1.724 \pm 0.094_{stat+syst}\ {}^{+0.101}_{-0.090}\,{}_{SF}\ {}^{+0.002}_{-0.011}\,{}_{theory}$	GGOU
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$2.108 \pm 0.120_{stat+syst}\ {}^{+0.184}_{-0.156}\,{}_{SF}\ {}^{+0.171}_{-0.177}\,{}_{theory}$	BLNP
$1.721 \pm 0.093_{stat+syst}\ {}^{+0.124}_{-0.106}\,{}_{SF}\ {}^{+0.008}_{-0.012}\,{}_{theory}$	GGOU
m_c constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$2.464 \pm 0.139_{stat+syst}\ {}^{+0.206}_{-0.175}\,{}_{SF}\ {}^{+0.178}_{-0.173}\,{}_{theory}$	BLNP
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$2.345 \pm 0.134_{stat+syst}\ {}^{+0.222}_{-0.189}\,{}_{SF}\ {}^{+0.169}_{-0.164}\,{}_{theory}$	BLNP

Results for $|V_{ub}|$
(the range pe=2.0-2.6GeV/c was used)

BABAR preliminary

$\lvert V_{ub}\rvert \times 10^3$	model
$4.052 \pm 0.147_{stat+syst}\ {}^{+0.297}_{-0.210}\,{}_{SF}\ {}^{+0.145}_{-0.139}\,{}_{theory}$	DN
$4.086 \pm 0.146_{stat+syst}\ {}^{+0.153}_{-0.151}\,{}_{theory}$	DGE
m_c constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$4.527 \pm 0.157_{stat+syst}\ {}^{+0.196}_{-0.188}\,{}_{SF}\ {}^{+0.246}_{-0.221}\,{}_{theory}$	BLNP
$4.162 \pm 0.143_{stat+syst}\ {}^{+0.148}_{-0.137}\,{}_{SF}\ {}^{+0.094}_{-0.171}\,{}_{theory}$	GGOU
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$4.403 \pm 0.153_{stat+syst}\ {}^{+0.258}_{-0.237}\,{}_{SF}\ {}^{+0.234}_{-0.212}\,{}_{theory}$	BLNP
$4.138 \pm 0.141_{stat+syst}\ {}^{+0.189}_{-0.179}\,{}_{SF}\ {}^{+0.196}_{-0.194}\,{}_{theory}$	GGOU
m_c constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$4.654 \pm 0.157_{stat+syst}\ {}^{+0.218}_{-0.197}\,{}_{SF}\ {}^{+0.246}_{-0.214}\,{}_{theory}$	BLNP
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$4.518 \pm 0.155_{stat+syst}\ {}^{+0.269}_{-0.247}\,{}_{SF}\ {}^{+0.233}_{-0.203}\,{}_{theory}$	BLNP

Results for $|V_{ub}|$
(the range pe=0.8-2.6GeV/c was used)

BABAR preliminary

$\|V_{ub}\| \times 10^3$	model
$3.881 \pm 0.113_{stat+syst}\,{}^{+0.287}_{-0.212}\,{}_{SF} \pm 0.120_{theory}$	DN
$3.926 \pm 0.111_{stat+syst}\,{}^{+0.083}_{-0.079}\,{}_{theory}$	DGE
m_c constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$4.452 \pm 0.128_{stat+syst}\,{}^{+0.200}_{-0.192}\,{}_{SF}\,{}^{+0.177}_{-0.191}\,{}_{theory}$	BLNP
$4.026 \pm 0.110_{stat+syst}\,{}^{+0.159}_{-0.149}\,{}_{SF}\,{}^{+0.003}_{-0.013}\,{}_{theory}$	GGOU
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 1.5GeV$	
$4.321 \pm 0.123_{stat+syst}\,{}^{+0.261}_{-0.241}\,{}_{SF}\,{}^{+0.172}_{-0.186}\,{}_{theory}$	BLNP
$4.003 \pm 0.108_{stat+syst}\,{}^{+0.197}_{-0.184}\,{}_{SF}\,{}^{+0.009}_{-0.014}\,{}_{theory}$	GGOU
m_c constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$4.604 \pm 0.130_{stat+syst}\,{}^{+0.229}_{-0.206}\,{}_{SF}\,{}^{+0.163}_{-0.164}\,{}_{theory}$	BLNP
$X_s\gamma$ constraint fit of SF parameters with $\mu_i = 2.0GeV$	
$4.462 \pm 0.127_{stat+syst}\,{}^{+0.273}_{-0.251}\,{}_{SF}\,{}^{+0.158}_{-0.159}\,{}_{theory}$	BLNP