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Exclusive Semileptonic B decays at BaBar

Marcello Rotondo
Universita' di Padova & INFN

BaBar Collaboration

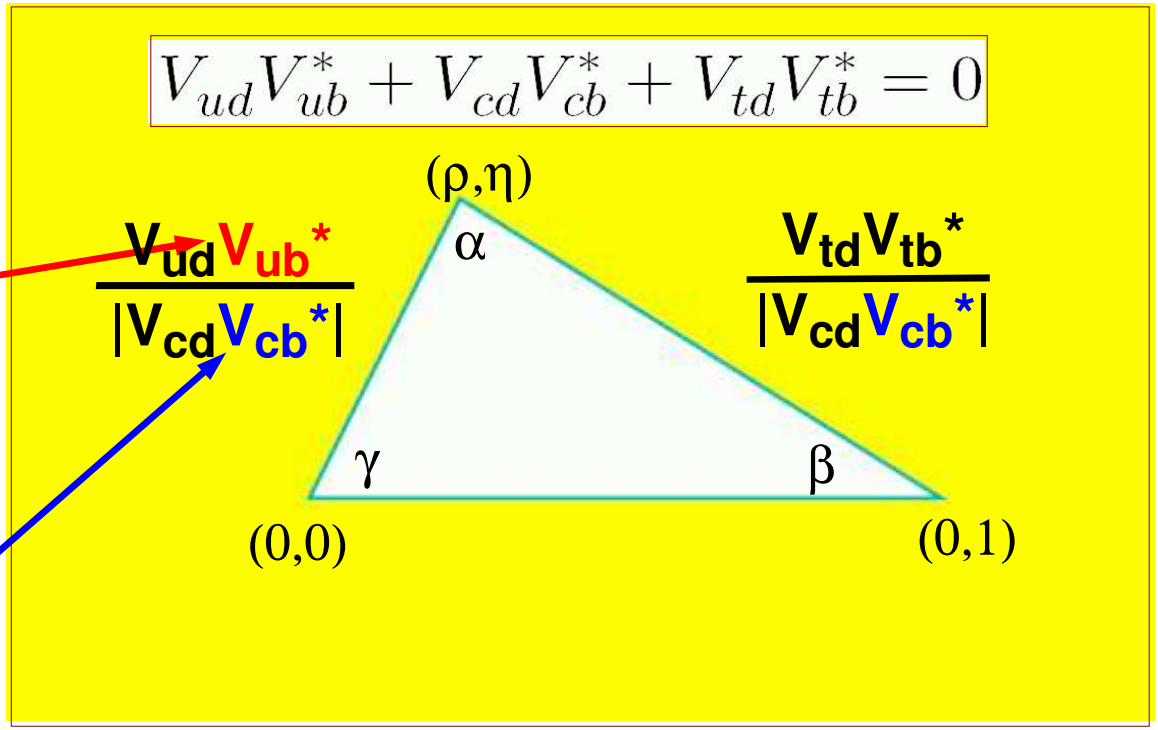
Outline

CKM Matrix and unitarity relations

Semileptonic B decays provide observables for V_{xb} CKM elements extraction

Exclusive $B^0 \to \rho^- l\, \nu$ *published on PRL* & $B^+ \to \pi^0, \rho^0, \omega\, l\, \nu$ *preliminary result of Br*

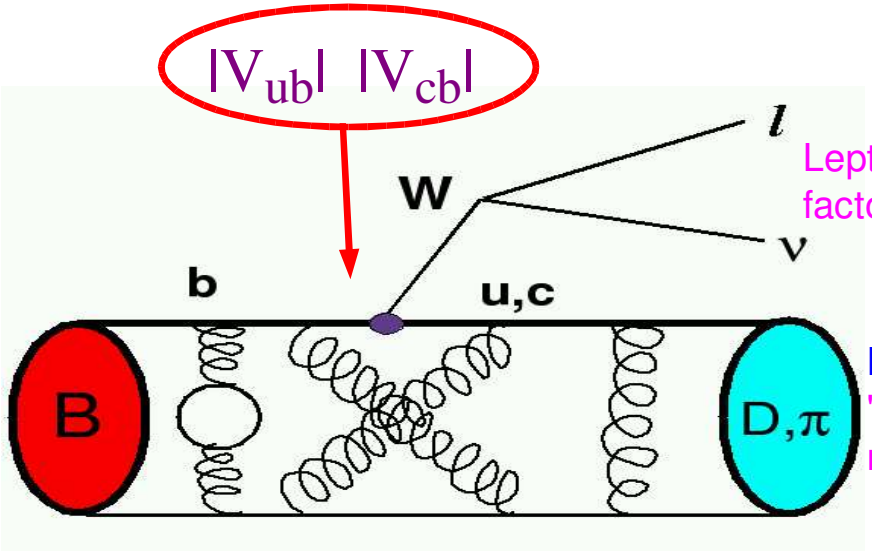
Exclusive $B^0 \to D^* l \nu$ *preliminary result*



Decays studied using $e^+e^- \to Y(4S)$ events

Measurements based on:
- ~80 fb^{-1} at the Y(4S) mass
- ~ 9 fb^{-1} 40 MeV below

How to measure $|V_{cb}|$ & $|V_{ub}|$?



Leptonic current factorizable

Low energy QCD 'only' inside the mesons

QCD corrections needed to exctract the EW physics
Exclusive methods:
B->D,π,ρ,ω **current** parameterized with Form Factors

$$\frac{d\Gamma}{dq^2} \propto |V_{xb}|^2 \mathcal{F}^2(q^2)\mathcal{G}(q^2)$$

pseudoscalar meson 1 FF
vector meson 3 FF

$B \rightarrow D, D^*$
HQS & HQET

$B \rightarrow \pi, \rho, \omega$
light quark in the final state!

Main source of uncertainties for the $|V_{xb}|$ extraction

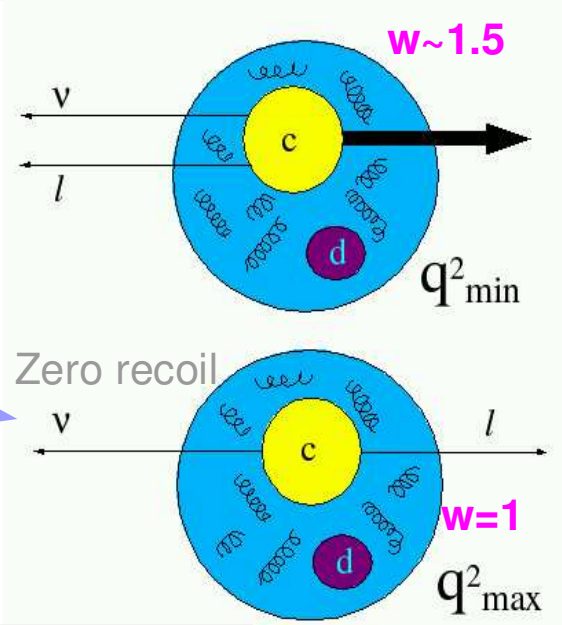
$|V_{cb}|$ with $B \to D^* l\nu$ decay

$$\frac{d\Gamma}{dw} \propto |V_{cb}|^2 \mathcal{F}^2(w)\mathcal{G}(w)$$

$$w = v_B \cdot v_{D^*} = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

$B \to D^*$ Form Factor (3 f.f.)

D* boost in the B rest frame



- HQS:

$m_Q \to \infty$ limit at **zero recoil** $\mathcal{F}(1) \to \xi(1)=1$
(Isgur-Wise)

- Zero recoil: rate → 0

$B \to D^* l\nu$ helicity suppression $(w-1)^{1/2}$
at **Y(4S)** reconstruction efficiency → 0 (charged soft pion)

Strategy:

Measure $d\Gamma/dw$, extrapolate to w=1 → $\mathcal{F}(1)|V_{cb}|$

- HQET provide shapes $\mathcal{F}(w)$
- Lattice QCD correction to $\mathcal{F}(1)$

Exclusive $|V_{cb}|$: extrapolation to w=1

- $\mathcal{F}(w)=\mathcal{F}(1)(1 + \rho^2(w-1) + c(w-1)^2 + O(w-1)^3)$
- Dispersion relations: constraints to the shape [$c=f(\rho^2)$]

Boyd Grinstein Lellouch
Phys. Rev. D56
Caprini Lellouch Nebert
Nucl. Phys. B530

$$\frac{d\Gamma}{dw} \propto |V_{cb}|^2 A_1^2(w) \left\{ 2\frac{1-2wr+r^2}{(1-r)^2}\left[1+\frac{w-1}{w+1}R_1(w)^2\right] + \left[1+\frac{w-1}{1-r}(1-R_2(w))\right]^2 \right\}$$

$$A_1(w) = A_1(1)\left[1-8\rho_{A_1}^2 z + (53\rho_{A_1}^2 - 15)z^2 - (231\rho_{A_1}^2 - 91)z^3\right] \qquad z = \frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}$$

FIT: 2 free parameters $\mathcal{F}(1)|V_{cb}|$ & ρ_A^2 strongly correlated

QCD sum rules → R1 & R2 shapes

$$R_1(\omega) \approx 1.27 - 0.12(\omega-1) + 0.05(\omega-1)^2 \qquad R_2(\omega) \approx 0.80 + 0.11(\omega-1) - 0.06(\omega-1)^2$$

CLEO measurements at w=1

$$R_1(1) = 1.18 \pm 0.30 \pm 0.12 \qquad R_2(1) = 0.71 \pm 0.22 \pm 0.07$$

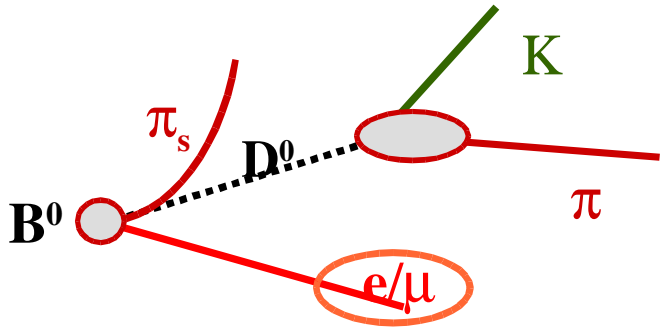
Most important source of systematic error on ρ_A^2

Exclusive $|V_{cb}|$: $B^0 \to D^{*-} l^+ \nu$ sample

$B^0 \to D^{*-} l^+ \nu$ reconstruction

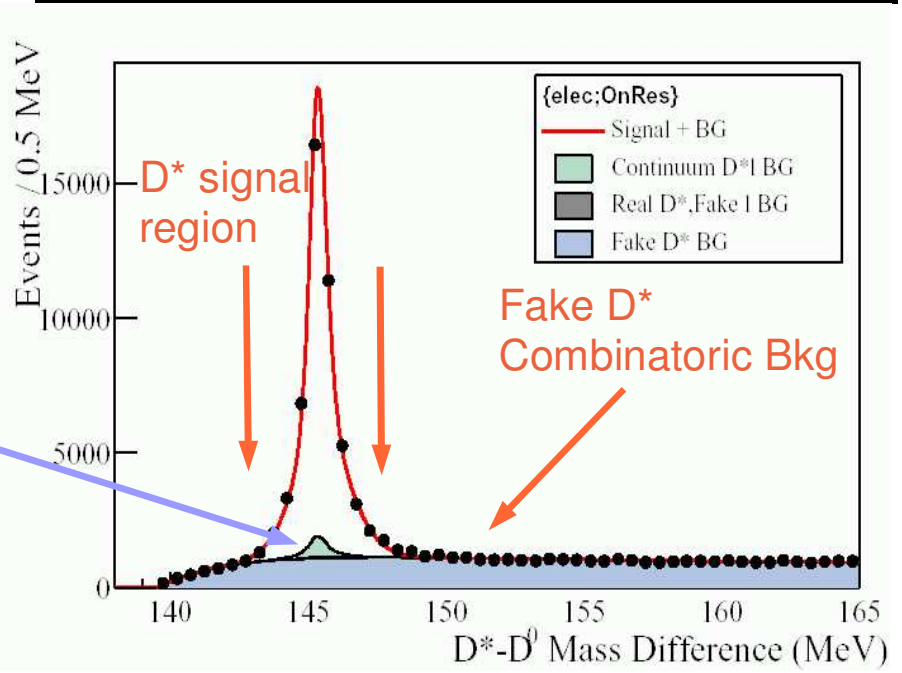
- $D^{*-} \to D^0 \pi^-_{soft}$
- $D^0 \to K\pi, K3\pi, K\pi\pi^0$

High energy lepton:
e & μ with $P_l > 1.2$GeV/c



•Constrained vertex fit on D^0 decay products, soft pion and lepton

Decay mode	BR (%)
$D^{*\pm} \to D^0\pi^\pm$	67.7 ± 0.5
$D^0 \to K\pi$	3.80 ± 0.09
$D^0 \to K\pi\pi\pi$	7.46 ± 0.31
$D^0 \to K\pi\pi^0$	13.1 ± 0.9



Combinatoric: ΔM side band

Continuum $e^+e^- \to qq \to D^*X$: off peak data

Fake lepton: tracks failing lepton-ID

Correlated: $B^0 \to D^*Xc/\tau$

$B_1 \to D^*X$, $B_2 \to lY$ (uncorrelated)

$B \to D^*Xl\nu$ (D** background)

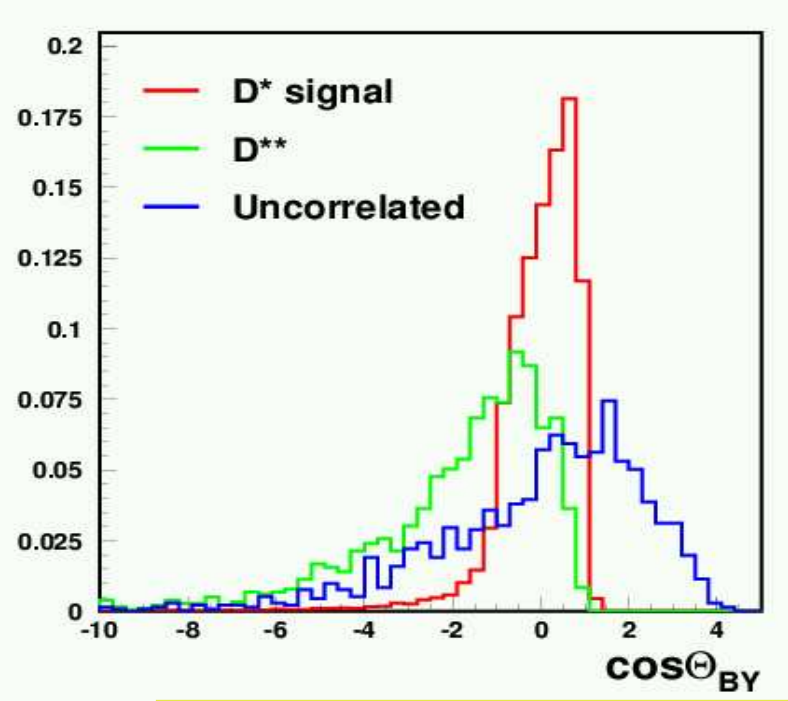
Next slide

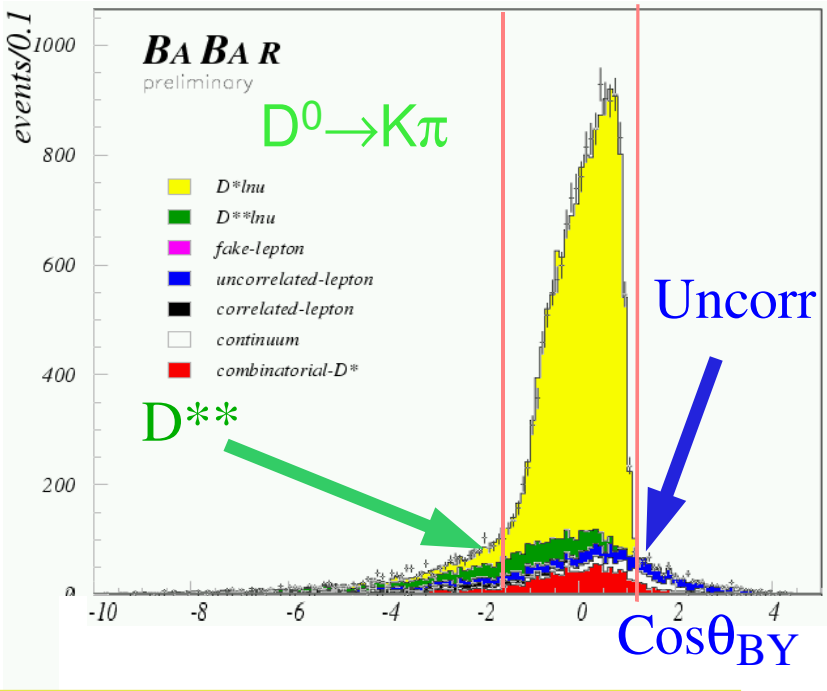
55.000 events in the signal region!

Peaking background evaluation: D** & Uncorr.

$$\cos\theta_{B^0,D^*\ell} = \frac{-(m^2_{B^0} + m^2_{D^*\ell} - 2\,E_{B^0}E_{D^*\ell}) + m^2_{X\nu}}{2\,|\vec{p}_{B^0}||\vec{p}_{D^*\ell}|}$$

Fixed to 0 in the ν hypothesis





→ determine the **fraction of D**** & **uncorrelated** fitting $\cos\theta_{B,Y}$

→ fit performed in **each w bin**

→ constrain D**/D* and Uncorr/D* ratios to be the same for each lepton and D^0 mode

Exclusive $|V_{cb}|$: dN/dw fit results

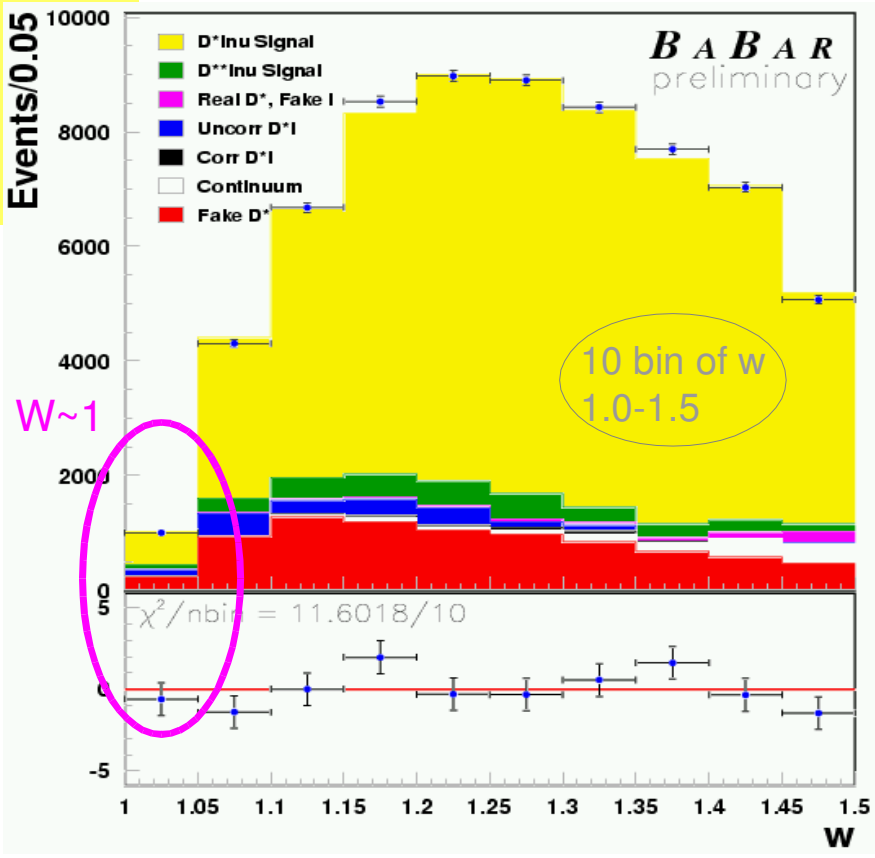
$$\frac{d\mathcal{N}}{dw} = 4\, N_{\Upsilon}\, f_{00}\, \mathcal{B}(D^{*+} \to D^0 \pi^+_{slow})\, \mathcal{B}(D^0 \to K^- n\pi)\, \epsilon(w)\, \frac{d\mathcal{B}}{dw}$$

$\mathcal{F}(1)|V_{cb}| = (34.03 \pm 0.24_{stat} \pm 1.31_{syst}) \times 10^{-3}$

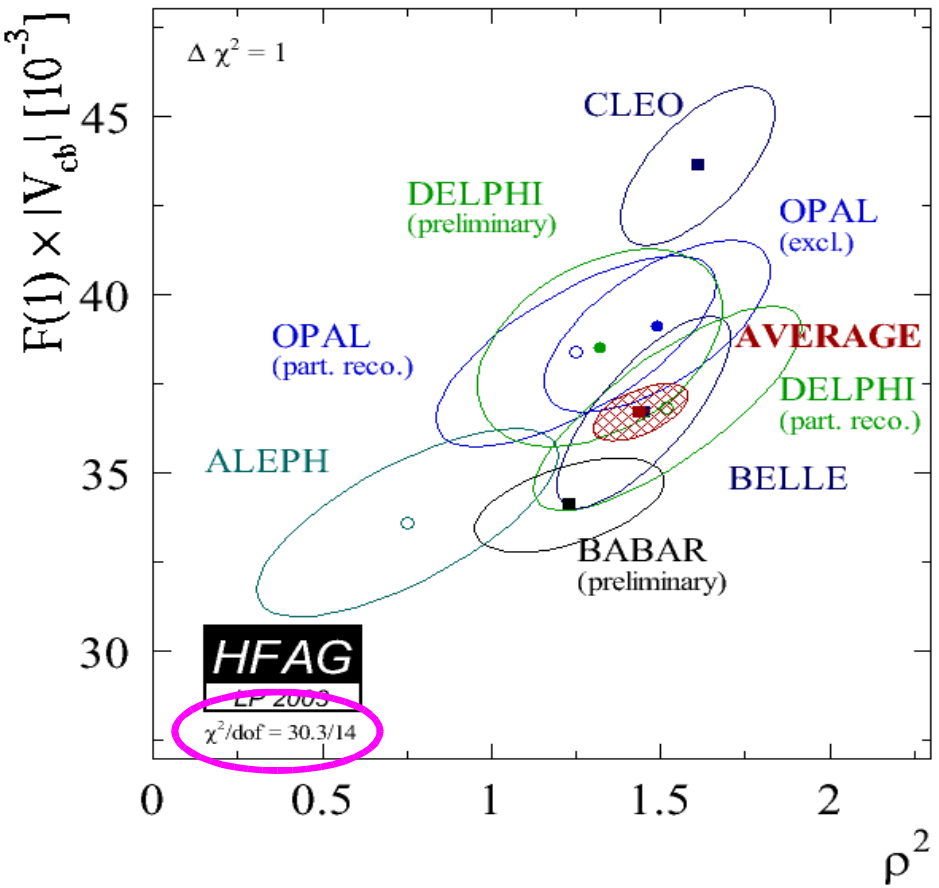
$\rho_A^2 = 1.23 \pm 0.02_{stat} \pm 0.28_{syst}$

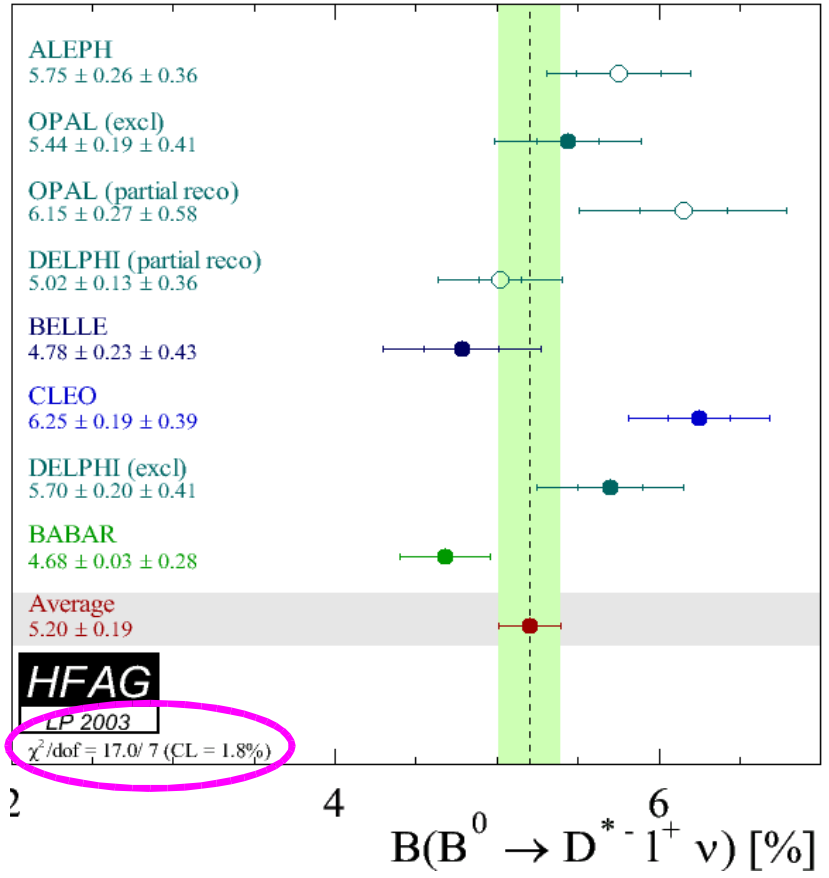
$\mathcal{B}(B^0 \to D^* l\nu) = (4.69 \pm 0.02 \pm 0.24)\%$

error contribution	$\delta\mathcal{F}(1)\|V_{cb}\|/\mathcal{F}(1)\|V_{cb}\| * 10^{-3}$	$\delta\mathcal{B}/\mathcal{B}(\%)$
statistics	0.7	0.8
π_{slow} efficiency	1.3	1.9
tracking efficiency	1.3	2.7
D^{**} background composition	1.8	2.0
$R_1(1)$ and $R_2(1)$	1.8	1.8
.....	.....	....
Total sys uncorrelated	3.4	5.0
$\mathcal{B}(\Upsilon(4S) \in B^0\bar{B}^0)$	1.3	2.7
.....	.....	....
Total sys correlated	1.8	3.5



Exclusive $|V_{cb}|$: comparison of $F(1)|V_{cb}|$





$\mathcal{F}(1)|V_{cb}|=(36.7 \pm 0.8)\times10^{-3}$

$\rho_A^2=1.44 \pm 0.14$

$Br=(5.20 \pm 0.19)\%$

Exclusive $B^{+/0} \to \rho^{0/+} l^- \nu$ decays: selection

- $B \to \rho^{\pm} l \nu$, $B \to \rho^0 l \nu$, $B \to \omega l \nu$
- Neutrino reconstruction
  - Require hermeticity

Analysis optimized for $\rho^{\pm} l \nu$

$$\vec{p}_{\mathrm{miss}} = -\sum_{\mathrm{tracks}} \vec{p}_i - \sum_{\mathrm{photons}} \vec{p}_i$$

- Extraction of the Yields:
  - Fit the $M_{\pi\pi(\pi)}$ vs ΔE ($=E_{had}+E_e+E_\nu-E_{beam}$) in **2 coarse bin of p_l**
  - High efficiency but **sensitivity in the region p_l>2.3GeV/c**
- Isospin/quark-model constraints:

$$\Gamma(B^0 \to \rho^-) = 2\Gamma(B^+ \to \rho^0) \sim 2\Gamma(B^+ \to \omega)$$

Exclusive $B^{+/0} \to \rho^{0/+} l^- \nu$ decays

$B^0 \to \rho^- e^+ \nu$

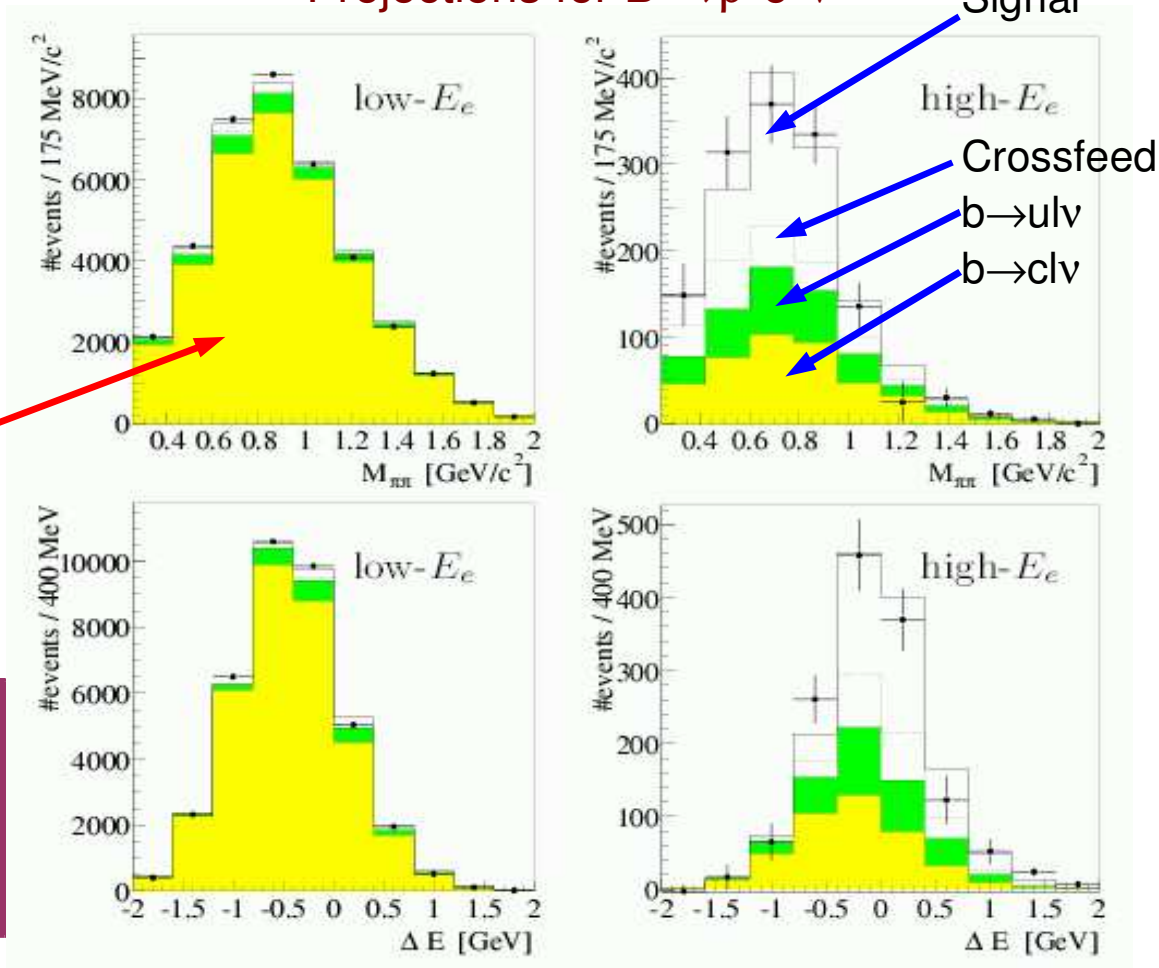
$B^+ \to \rho^0 e^+ \nu$

High E_l: 2.3-2.7 GeV
signal enriched

Low E_l: 2.0-2.3 GeV
background extimation

Yield in the High E_l region
$B \to \rho^+$ -> 505 ± 63
$B \to \rho^0$ -> 321 ± 40

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



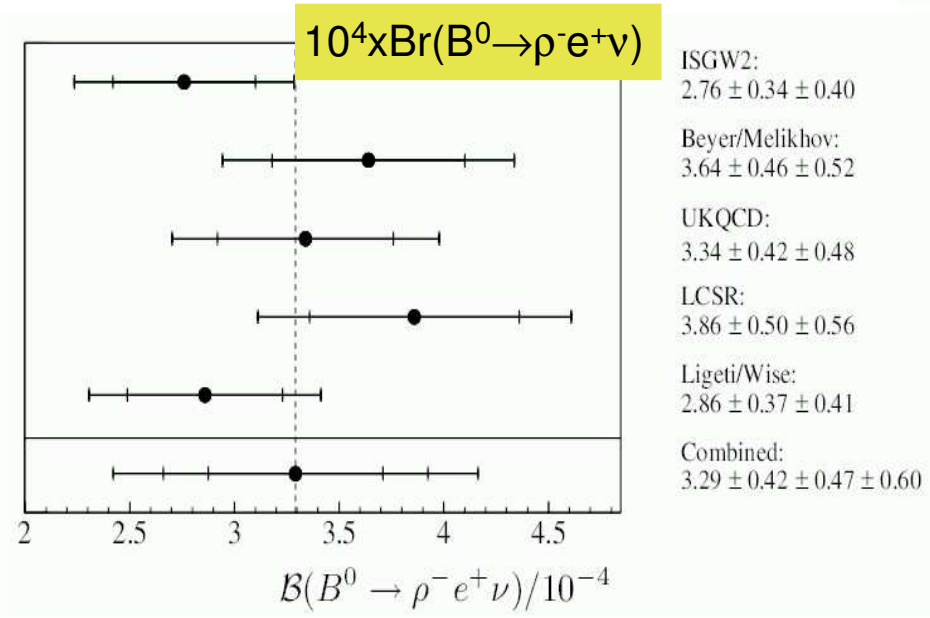
Continuum subtracted plots
Continuum is the larghest source of background

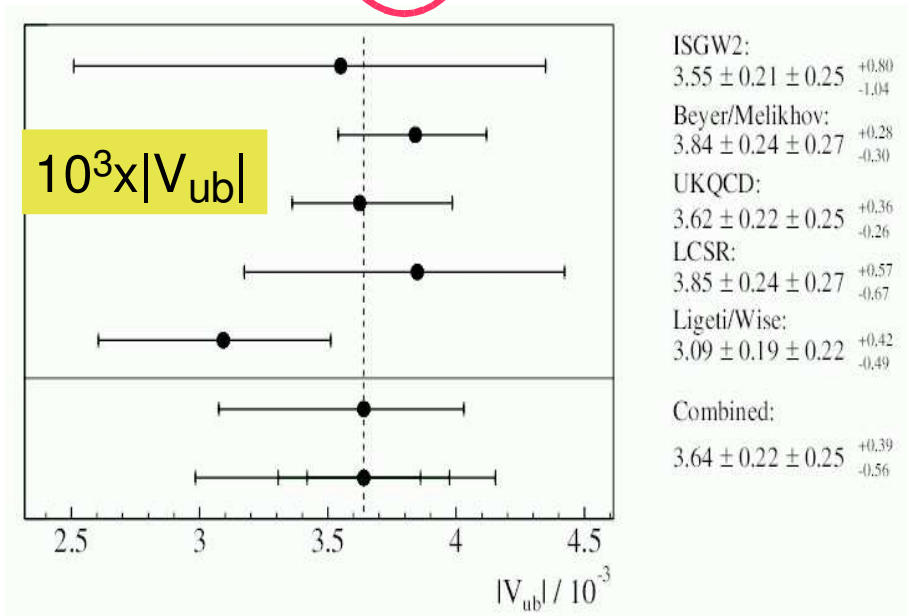
Exclusive $B^{+/0} \to \rho^{0/+} l^- \nu$: BR & $|V_{ub}|$

[1] PRD52,2783
[2] PLB436,344
[3] PLB416,392
[4] PRD58,094016
[5] PRD53,4937

$$|V_{ub}| = \sqrt{\mathcal{B}(B^0 \to \rho^- e^+ \nu) / (\tilde{\Gamma}_{\rm th} \tau_{B^0})}$$

Form factors	$\tilde{\Gamma}_{\rm th}$ (ps^{-1})	Error (%)	Reference
ISGW2	14.2	±50	[1]
Beyer/Melikhov	16.0	±15	[2]
UKQCD	16.5	+21, −14	[3]
LCSR	16.9	±32	[4]
Ligeti/Wise	19.4	±29	[5]





$$|V_{ub}| = (3.64 \pm 0.22 \pm 0.25\ ^{+.39}_{-.56})\times 10^{-3}$$

Exclusive $B^+ \to \pi^0, \rho^0, \omega\, l\, \nu$ decays

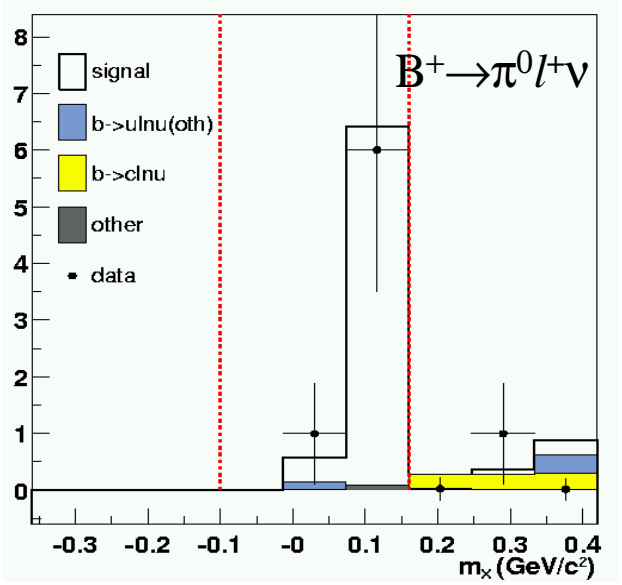
B recoil technique: as in inclusive V_{ub} analysis

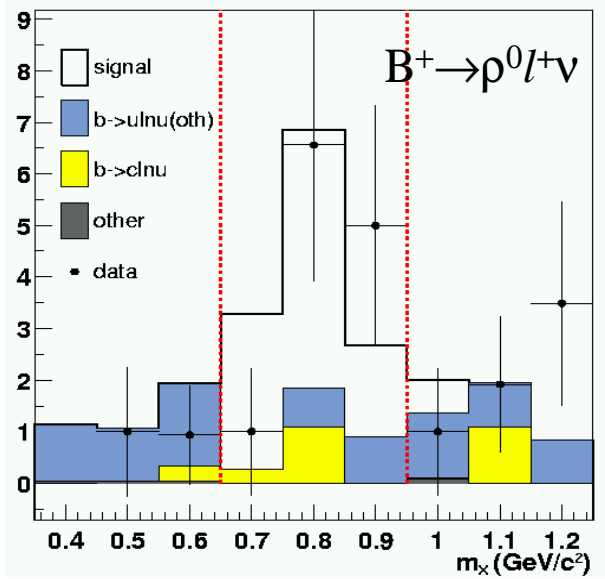
- Small statistics
- Very high purity
- Loose cuts

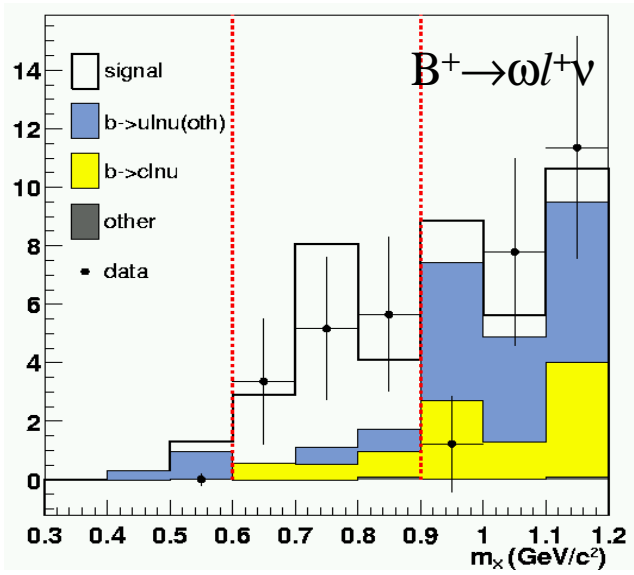
  → small model dependence

$$\begin{cases} \mathcal{B}(B^+ \to \pi^0 l^+ \nu) = (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to "\rho^0" l^+ \nu) = (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to \omega l^+ \nu) = (2.20 \pm 0.92_{stat} \pm 0.57_{syst}) \cdot 10^{-4} \end{cases}$$

Projection of the results on the Mx variable







Summary I: V_{cb}

- **$|V_{cb}|$ via differential analysis with** $B^0 \to D^* l\nu$

$BR(B^0 \to D^* l\nu) = (4.69 \pm 0.02 \pm 0.24)\%$

$\mathcal{F}(1)|V_{cb}| = (34.03 \pm 0.24_{stat} \pm 1.31_{syst}) \times 10^{-3}$

$|V_{cb}| = (37.27 \pm 0.26_{stat} \pm 1.43_{syst}\ ^{+1.50}_{-1.20\ F(1)}) \times 10^{-3}$

Preliminary result hep-ex/0308027

$\mathcal{F}(1) = 0.913^{+0.030}_{-0.035}$ Lattice QCD

  - **Experimental error O(4%)**
- Very large sample
  - Small statistical error
  - Background constrained from Data

Summary II: V_{ub}

- **$|V_{ub}|$ analysis with $B \to \rho^{\pm} l \nu$ experimental error 9%**

$$BR(B \to \rho^{\pm} l \nu) = (3.29 \pm 0.42 \pm 0.47 \pm 0.60) \times 10^{-4}$$

$$|V_{ub}| = (3.64 \pm 0.22 \pm 0.25 \,{}^{+.39}_{-.56}) \times 10^{-3}$$

PRL.90:181801

- BR of many charmless semileptonic B decays with **fully reconstructed events**

$$\begin{cases} \mathcal{B}(B^+ \to \pi^0 l^+ \nu) = (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to "\rho^0" l^+ \nu) = (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to \omega l^+ \nu) = (2.20 \pm 0.92_{stat} \pm 0.57_{syst}) \cdot 10^{-4} \end{cases}$$

Preliminary result
LP03

  - Working on converting BR in V_{ub}
  - Promising with the increase of the luminosity

Backup slides

$B^0 \to D^{*-} l^+ \nu$: reconstruction of w

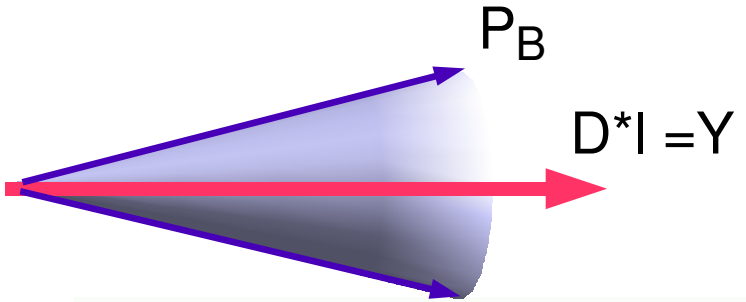
$$w = v_B \cdot v_{D^*} = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

$q^2 = (p_B - p_{D^*})^2 = (p_l + p_\nu)^2$

Problem: we ignore the **B** direction (2 unknowns)

one constraint: $m_\nu = 0$

$$\cos(\theta_{B^0 Y}) = \frac{-(M_{B^0}^2 + M_Y^2 - 2 E_{B^0} E_Y)}{2 p_{B^0} p_Y}$$

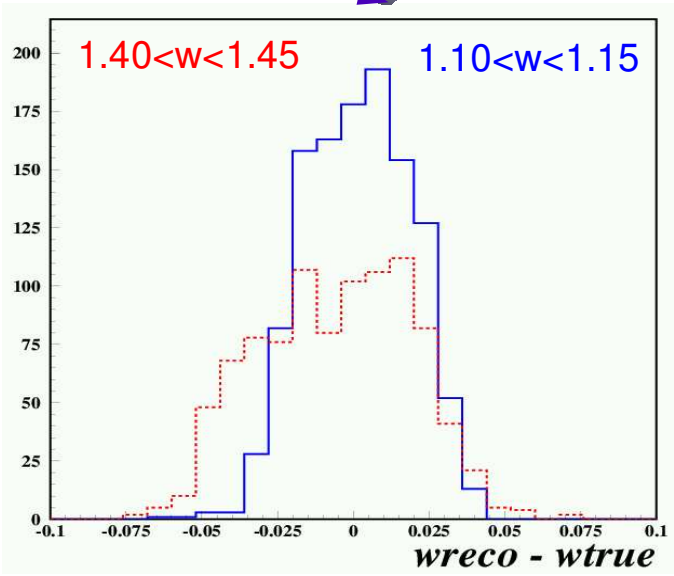


Consider extreem solutions:

- **max** and **min** angle between B and D*

consistent with cos(BY) and cos(D*Y)

$$\tilde{w} = \frac{w_{min} + w_{max}}{2}$$



$B^0 \to D^{*-} l^+ \nu$: selection cuts

- Lepton Candidates from GoodTrackList
  - Plep>1.2GeV/c
  - PID: veryTight selector
- D^0 tracks from GoodTrackLoose: 12 hits in the DCH
  - Kaon: not a Pion for Kpi, Tight for Kpipi0 and K3pi
- Pi soft:
  - $p_{\pi\ soft} < 450$ MeV and $p^t_{\pi\ soft} > 50$ MeV
- D* candidate
  - Vertex fit χ^2>1%
  - 144 MeV < δM < 147 MeV (SVT+DCH)
  - 143 MeV < δM < 148 MeV (SVT only)
- $\cos \theta_{D^* l} < 0$ (Opposite Side sample)
- $|\cos\theta_{B,Y}|<1.2$

$B^0 \to D^{*-} \ell^+ \nu$: D** systematic errors

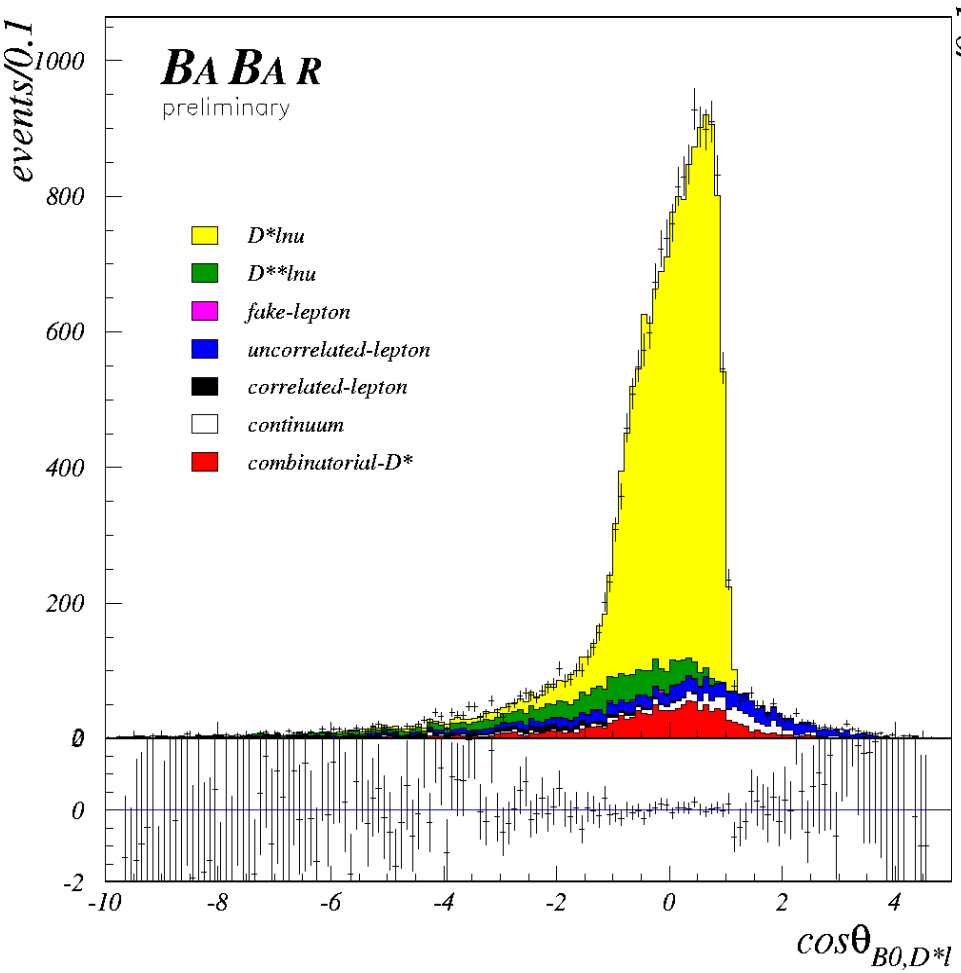
B decay mode	B $\times 10^{-2}$	Model	D^{**} decay	$\mathcal{B}$	Overall BR $\times 10^{-4}$
$B^0 \to D^{*-}\pi^0\ell^+\nu_\ell$	0.10	GR	–	–	10.
$B^0 \to D_1^-\ell^+\nu_\ell$	0.56	ISGW2	$D_1^- \to D^{*-}\pi^0$	0.33	18.5
$B^0 \to D_1^{*-}\ell^+\nu_\ell$	0.37	ISGW2	$D_1^{*-} \to D^{*-}\pi^0$	0.33	12.2
$B^0 \to D_2^{*-}\ell^+\nu_\ell$	0.37	ISGW2	$D_2^{*-} \to D^{*-}\pi^0$	0.103	3.81
$B^0 \to D'^-\ell^+\nu_\ell$	0.02	ISGW2	$D'^- \to D^{*-}\pi^0$	0.33	0.67
$B^0 \to D^{*\prime-}\ell^+\nu_\ell$	0.22	ISGW2	$D^{*\prime-} \to D^{*-}\pi^0$	0.17	3.74
$B^+ \to D^{*-}\pi^+\ell^+\nu_\ell$	0.20	GR	–	–	20.
$B^+ \to D_1^0\ell^+\nu_\ell$	0.56	ISGW2	$D_1^0 \to D^{*-}\pi^+$	0.67	37.5
$B^+ \to D_1^{*0}\ell^+\nu_\ell$	0.37	ISGW2	$D_1^{*0} \to D^{*-}\pi^+$	0.67	24.8
$B^+ \to D_2^{*0}\ell^+\nu_\ell$	0.37	ISGW2	$D_2^{*0} \to D^{*-}\pi^+$	0.21	7.78
$B^+ \to D'^0\ell^+\nu_\ell$	0.02	ISGW2	$D'^0 \to D^{*-}\pi^+$	0.67	1.32
$B^+ \to D^{*\prime0}\ell^+\nu_\ell$	0.22	ISGW2	$D^{*\prime0} \to D^{*-}\pi^+$	0.33	7.26

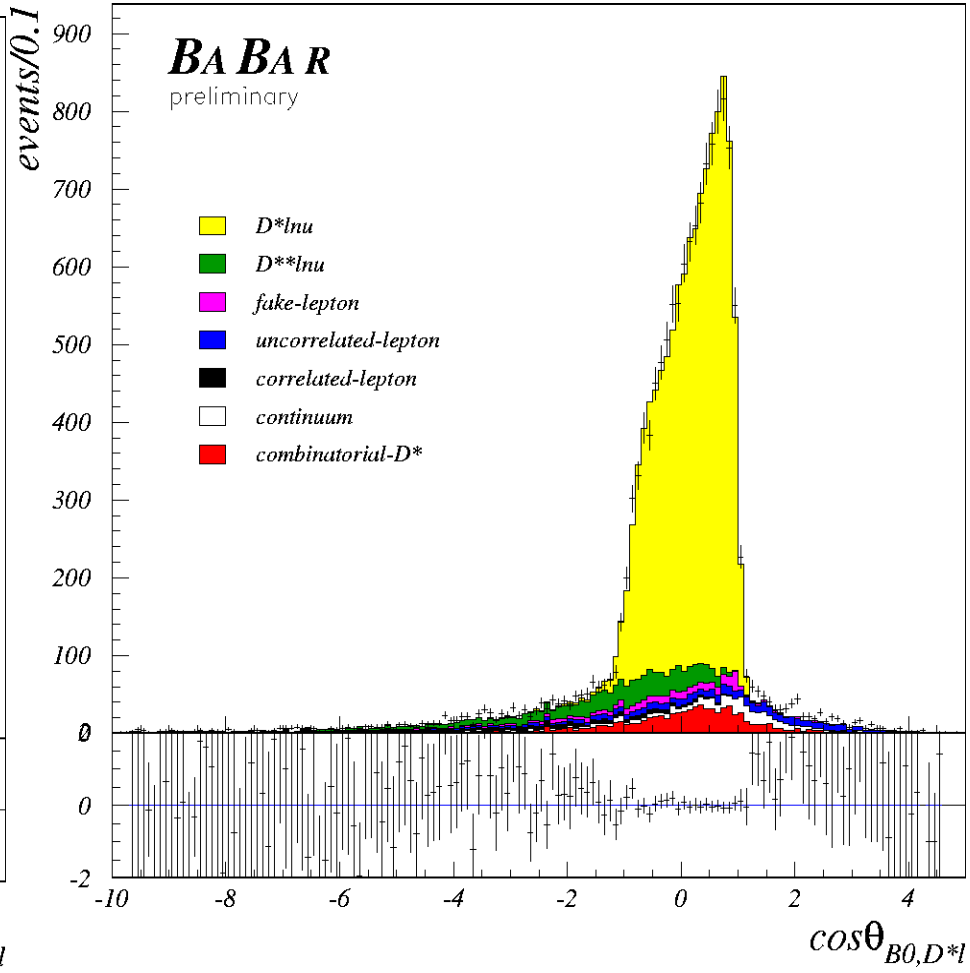
Systematic error:

assuming only one mode a time;

repeat the cosBY and w fit: half the max and min values of the parameters

D**


BABAR
preliminary
D*lnu
D**lnu
fake-lepton
uncorrelated-lepton
correlated-lepton
continuum
combinatorial-D*
events/0.1
cosθB0,D*l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