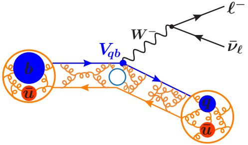
Recent Semileptonic results from *BaBar*



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Two new results shown for the first time at ICHEP 2014:

1. $B \to D^{**} \ell \bar{\nu}$

First observation of $B \to D \pi^+ \pi^- \ell \bar{\nu}_\ell$, evidence for $B \to D^* \pi^+ \pi^- \ell \bar{\nu}_\ell$.

Publication in preparation

2. $D \to \pi \ell \bar{\nu}$

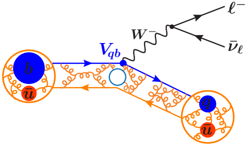
Precision measurement of $D \to \pi e \bar{\nu}_e$ in bins of q^2 + Form Factor analysis

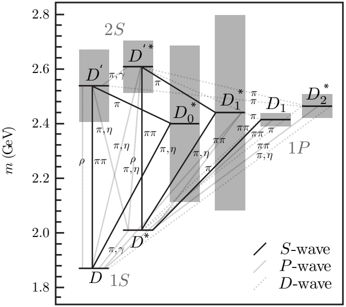
To be submitted

Exclusive $B \to X_c \, \ell \, \bar{\nu}_\ell$ and why D^{**} are an elusive contribution

Motivation to know $B \to X_c \, \ell \, \bar{\nu}_\ell$ precisely

1. Access to $|V_{cb}|$
2. Test for new physics ($B \to X_c \, \tau \, \bar{\nu}$)
3. Important Bkg of $B \to X_u \, \ell \, \bar{\nu}_\ell$ ($|V_{ub}|$)





Decays into low mass X_c well known: D & D^*

Make up about **70%** of total inclusive $B \to X_c \, \ell \, \bar{\nu}_\ell$ rate

Decays into high mass X_c less well known: D_2, D_1, D_1', D_0

Make up about **15%** of total inclusive $B \to X_c \, \ell \, \bar{\nu}_\ell$ rate, measured in $D^{**} \to D^* \pi$

$\to$ This leaves a gap of about **15%** that is unknown, relevant background.

$\to$ Measured D_2, D_1, D_1', D_0 in conflict with expectation from HQET

There is some direct evidence that there should be a contribution with a signature of $B \to D^{(*)} \pi \pi \ell \bar{\nu}_\ell$:

* Belle and LHCb observed $D_1 \to D \pi\pi$ decays in hadronic $B \to D_1 X$ production.

  Phys. Rev. Lett. 94, 221805 (2005) and Phys. Rev. D 84, 092001 (2011)

* BABAR and LHCb observed new states compatible with the quantum numbers for 2S states.

  Phys. Rev. D 82, 111101 (2010) and Journal of High Energy Physics, Volume 2013, Issue 9

Overall interesting since such contributions would be a background for the BABAR $B \to D^{(*)} \tau \nu$ measurement

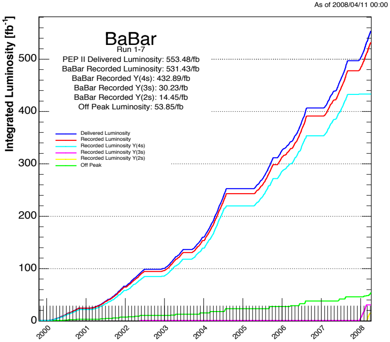
(in tension with the SM, excludes pretty much all of 2DHM phase space by 99% CL)

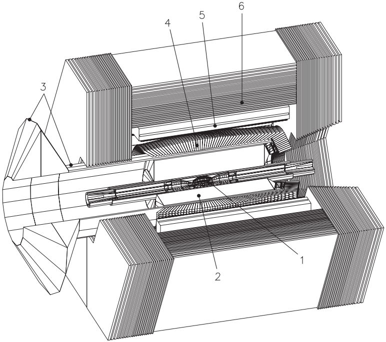
Could ease the conflict between the measured D_2, D_1, D_1', D_0 branching fractions this tension is called the 1/2 & 3/2 problem in the literature

BaBar was a multi-purpose detector operated at the PEP-II B-Factory

* e^+e^- collider at $\sqrt{s} = 10.58$ GeV
* Physics focus: CP violation, τ, charm, CKM matrix, ...

BaBar Integrated luminosity: 432/fb corresponding to about 470 million $B\bar{B}$ pairs





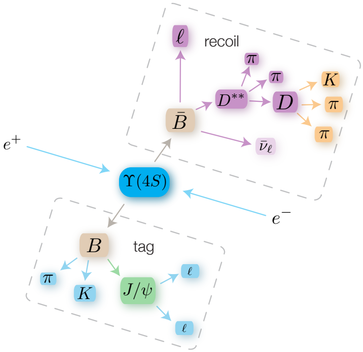
(1) silicon vertex tracker; (2) drift chamber; (3) Cherenkov detector; (4) electromagnetic calorimeter; (5) superconducting solenoid; (6) flux return and muon detector

Event reconstruction: tag & recoil approach

Fully reconstruct one B meson via hadronic decay modes:

Experiment	$B^0\ \bar{B}^0$	$B^+\ B^-$
BABAR	0.2%	0.4%
Belle	0.2%	0.3%

Table : Hadronic tag B reconstruction efficiencies as found in 1406.6311 [hep-ex]



Seed based reconstruction with 2968 possible decay modes.

Seed: D, D^*, D_s, D_s^*, J/ψ, supplemented with number of charged and neutral pions or kaons.

Standard cuts on beam constraint energy and mass.

$|\Delta E| = |E_{\text{B tag}} - \sqrt{s}/2|$; $m_{\text{ES}} = \sqrt{s/4 - \vec{p}^{\,2}_{\text{B tag}}}$ with $(E_{\text{B tag}}, vecp_{\text{B tag}})$ the four-momentum of the reconstructed B and $\sqrt{s}$ the centre-of-mass energy of the $e^+\ e^-$ pair.

Signal side reconstruction

Reconstruct lepton ($= e$ or μ) candidate and D or D^* candidates:

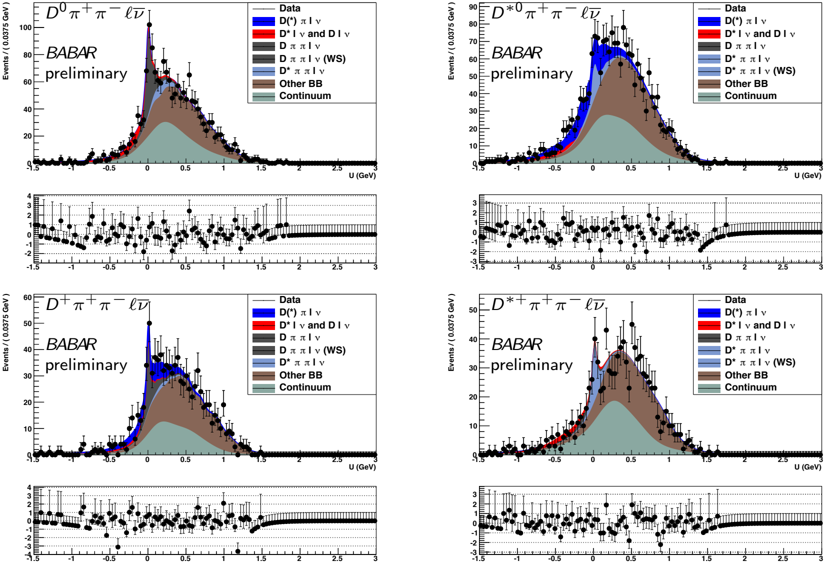
* Allow for maximal n additional charged tracks in the event for $B_{\text{reco}} \to D^{(*)}\, n\, \pi^{\pm}\, \ell\, \bar{\nu}$.
* In the case of many candidates select candidate with minimal beam constraint energy $|\Delta E|$.
* For n, require $\Delta m = m_{D^0\,\pi^{\pm}} - m_{D^0} > 0.16$ GeV to veto contributions from $B_{\text{reco}} \to D^{(*)}\,(n-1)\,\pi^{\pm}\,\ell\,\bar{\nu}$.
* Fisher discriminants to reduce $B\bar{B}$ and continuum $e^+\,e^-$ contributions.

Discriminating variable for Signal & Background fit built from reconstructed neutrino four-momentum: $E_{\text{miss}} - p_{\text{miss}} = E_{\text{B tag}} - E_{\text{B reco}} - |\vec{p}_{\text{B tag}} - \vec{p}_{\text{B reco}}|$

For a proper signal decay, this should peak at zero; missing particles cause a shoulder towards the positive side.

Unbinned maximum likelihood fits with PDFs built from simulated sampled using Gaussian kernel estimators.

Preliminary $B \to D^{(*)}\pi^+\pi^-\ell\bar{\nu}$ results



Preliminary $B \to D^{(*)}\pi^+\pi^-\ell\bar{\nu}$ results

Fitted signal yields:

BABAR preliminary

channel	signal yield	ϵ_{sig} [units of 10^{-4}]	$S \equiv \sqrt{2\Delta\mathcal{L}}$	S_{tot}
$D^0\pi^+\pi^-$	189 ± 39	0.989 ± 0.059	5.2	4.4
$D^+\pi^+\pi^-$	57 ± 20	0.567 ± 0.046	3.1	2.6
$D^{*0}\pi^+\pi^-$	75 ± 36	0.951 ± 0.058	2.1	1.9
$D^{*+}\pi^+\pi^-$	58 ± 19	0.457 ± 0.041	3.3	2.9

(S = statistical significance; S_{tot} = significance including systematic uncertainties; given uncertainties are statistical only)

Combined significance:

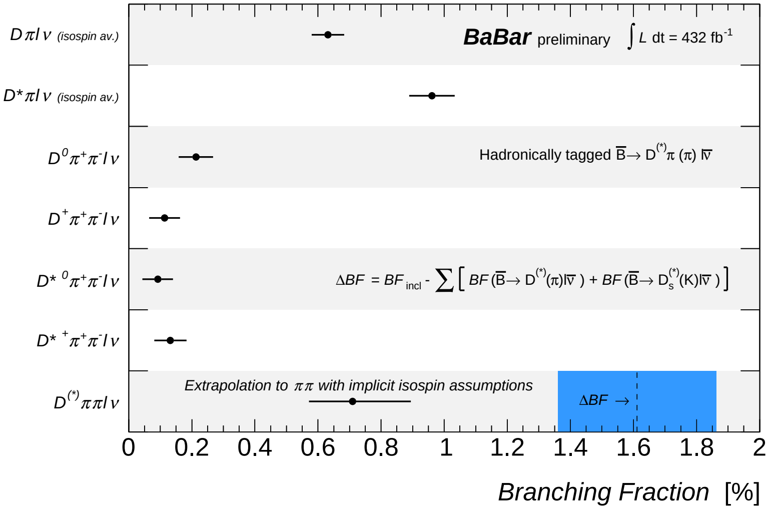
* **5.1** σ for $B \to D\pi^+\pi^-\ell\bar{\nu}$
* **3.5** σ for $B \to D^*\pi^+\pi^-\ell\bar{\nu}$

Conversion into branching fractions via $B \to D^{(*)}\ell\bar{\nu}$ as normalization channels

$$\frac{\mathcal{B}(B \to D^{(*)}\pi^+\pi^-\ell\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})} = \frac{N_{n\pi}^{(*)}}{N_{\mathrm{norm}}}\frac{\epsilon_{\mathrm{norm}}}{\epsilon_{n\pi}^{(*)}}$$

and for $\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})$ one can use then the world average from the PDG.

Summary for the Gap



$\to$ Can assign about 0.7% to $B \to D^{(*)}\,\pi\,\pi\,\ell\,\bar{\nu}$ production, reducing its significance from originally 7σ to 3σ.

Two new results shown for the first time at ICHEP 2014:

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The $D \to \pi \ell \bar{\nu}$ Form Factor and its connection to $|V_{ub}|$

Precision determination of $D \to \pi \ell \bar{\nu}$ interesting test for our understanding of QCD:

* Form factor can be calculated as a function of 4-momentum transfer squared of $D \to \pi$ system on the Lattice.

$\to$ Can also confront

With form factor prediction for $f_+(q^2 = 0)$ one can extract CKM matrix element $|V_{cd}|$

Using lattice information one can relate $D \to \pi$ form factors with $B \to \pi$ form factors and include the partial branching fractions into a global fit for $|V_{ub}|$.

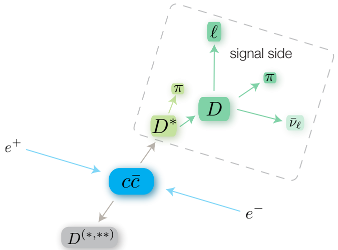
$\to$ Adds information at high q^2 where $B \to \pi \ell \bar{\nu}_\ell$ has limited precision

$\to$ Trade off between this additional information and difficult to assess 'translation' uncertainty between $D \to \pi$ and $B \to \pi$.

B-Factories are also $c\bar{c}$ factories:

$e^+e^- \to$	Cross-section (nb)
$b\bar{b}$	1.05
$c\bar{c}$	1.30
$s\bar{s}$	0.35
$u\bar{u}$	1.39
$d\bar{d}$	0.35
$\tau^+\tau^-$	0.94
$\mu^+\mu^-$	1.16
e^+e^-	~ 40

Production cross sections at $\sqrt{s} = 10.58$ GeV from *BABAR* physics book.



Uses 80% of the total *BABAR* integrated luminosity.

Reconstruct $D^{*+} \to D^0 \pi^+$ with $D^0 \to \pi^- e^+ \nu$:

* Reconstruct $p_D = p_\pi + p_e + p_\nu$ by using missing energy information from rest of event
* Make use on kinematic constraints on m_D and m_{D^*}

Use Fisher discriminants to reduce $B\bar{B}$ and other $c\bar{c}$ background.

As discriminating variable for Signal & Background use $\delta m = m_{D^*} - m_D$ in bins of the observable(s) of interest

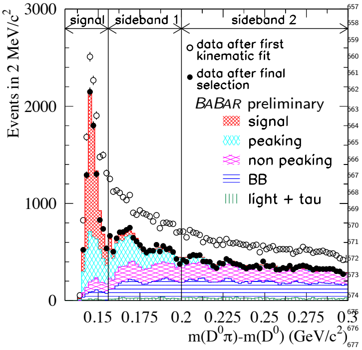
Four-momentum transfer squared of the D to the π system reconstructed as:

$$q^2 = (p_D - p_\pi)^2$$

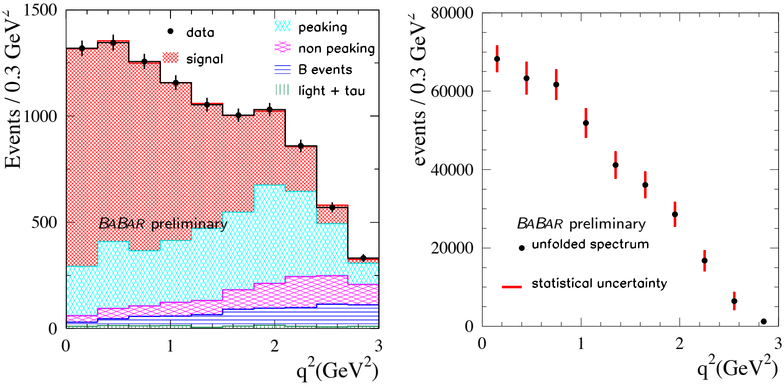
Cross check of method by reconstructing $\cos\theta_e^*$:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_e} \propto \sqrt{1-\cos\theta_e^2}$$

Exact in massless fermion limit.



Detector level prior background subtraction and unfolded q^2 distribution:



Unfolded with singular value decomposition (SVD) method

Events converted into branching fractions via $D^0 \to K^- \pi^+$ normalization channel:

$$\frac{\mathcal{B}(D^0 \to \pi^- e^+ \nu)}{\mathcal{B}(D^0 \to K^- \pi^+)} = \frac{N_{\pi^- e^+}}{N_{\rm norm}} \frac{\epsilon_{\rm norm}}{\epsilon_{\pi^- e^+}}$$

Fit with z-expansion to determine form factor normalization $\times |V_{cd}|$

$$|V_{cd}| \times f_+(q^2 = 0) = 0.137 \pm 0.004 \pm 0.002 \pm 0.001$$

Errors are statistical, systematic and from normalization channel

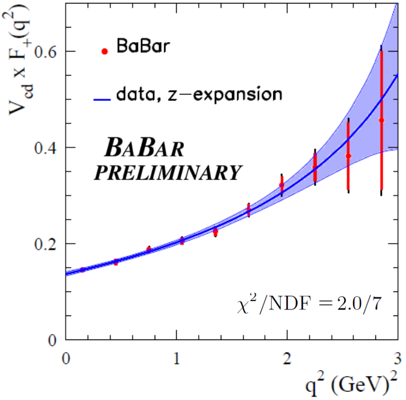
Heavy quark limit: $b \to q$ and $c \to q$ look identical wrt light degree freedom.

Finite quark masses and difference between m_b & m_c break this degeneracy.

Lattice QCD input can be used to relate the form factors to combine experimental information to determine $|V_{ub}|$

Method	$\lvert V_{ub}\rvert \times 10^{-3}$
Pole expansion	$2.6 \pm 0.2 \pm 0.4$
Direct Lattice ratio	$3.65 \pm 0.18 \pm 0.40$

Determined $|V_{ub}|$ when combined with available *BABAR* $B \to \pi \ell \bar{\nu}$ information



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Finite quark masses and difference between m_b & m_c break this degeneracy.

$$\frac{\Gamma(B\to\pi\,\ell\,\bar{\nu})}{\Gamma(D\to\pi\,\ell\,\bar{\nu})} = \frac{|V_{ub}|^2}{|V_{cd}|^2}\,\frac{m_B}{m_D}\,\frac{\left(f_+^{B\to pi}\right)^2}{\left(f_+^{B\to pi}\right)^2}$$

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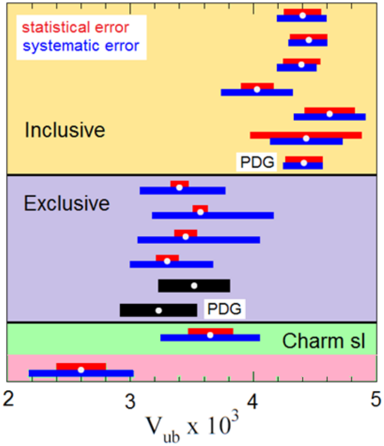


Summary: Two new & nice results from BaBar

$B \to D^{(*)}\,\pi\,\pi\,\ell\,\bar{\nu}_\ell$

* First observation of $B \to D\,\pi\pi\,\ell\,\bar{\nu}_\ell$ and evidence for $B \to D^*\,\pi\pi\,\ell\,\bar{\nu}_\ell$

$\rightarrow$ Important background for other $B \to X_c\,\ell\,\bar{\nu}_\ell$ analyses, helps closing the gap between inclusive & exclusive.

$D \to \pi\,\ell\,\bar{\nu}_\ell$

* Measurement of the $D \to \pi\,\ell\,\bar{\nu}_\ell$ partial branching fraction and measurement of the form factor

$\rightarrow$ Nice result by itself, explored possibility to combine $D \to \pi$ information with $B \to \pi$ to extract $|V_{ub}|$

$\rightarrow$ Theory uncertainties very difficult to assess, but none the less a very interesting avenue to test the consistency of different results.

Thank you!

Backup

Charm Spectroscopy

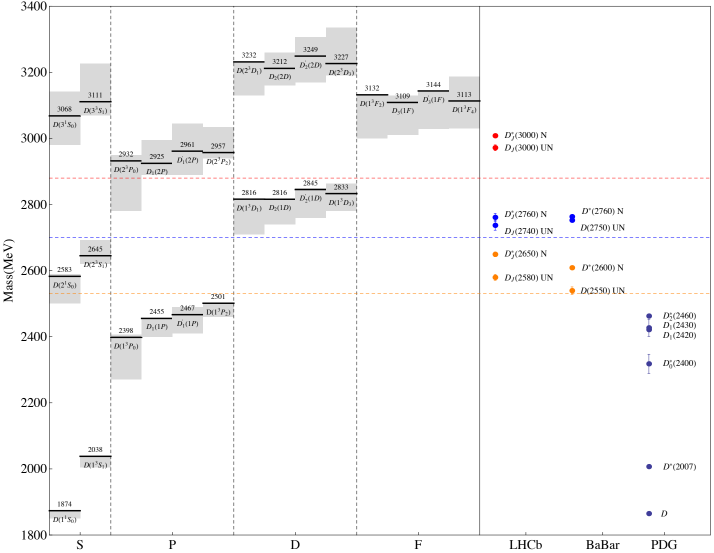
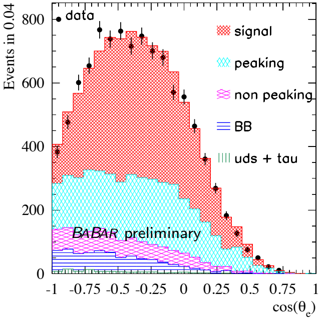
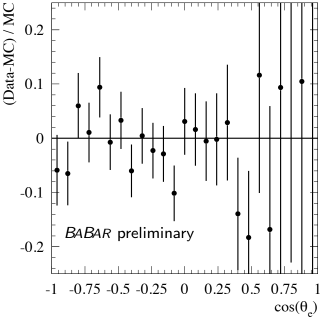


Figure from arXiv:1407.3092 [hep-ph]

$D \to \pi\, e\, \bar{\nu}_e$ helicity angle distribution





Helicity angle of the $e^{\pm}$ in the rest frame of the virtual W with respect to the W flight direction in the rest frame of the D meson.

$D \to \pi\, e\, \bar{\nu}_e$: Comparison with other results for f_+