Measurement of the Branching Fraction $B^+ \to \omega \ell^+ \nu_\ell$

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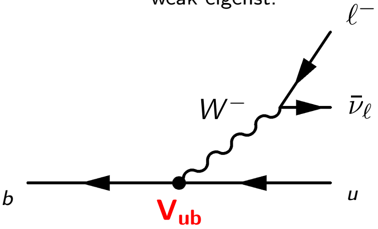
Why look at $B^+ \to \omega \ell^+ \nu_\ell$?

$$\underbrace{\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}}_{\text{weak eigenst.}} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\text{CKM-Matrix}} \underbrace{\begin{pmatrix} d \\ s \\ b \end{pmatrix}}_{\text{strong eigenst.}}$$



$$\mathcal{B}(b \to u \ell \nu) \propto |V_{ub}|^2$$

Typical Values

$\mathcal{B}(B \to u \ell \nu) \approx 10^{-4}$
Signal efficiency $\epsilon \approx 10^{-2}$
Need about 100 mio. B-Mesons for 100 signal events

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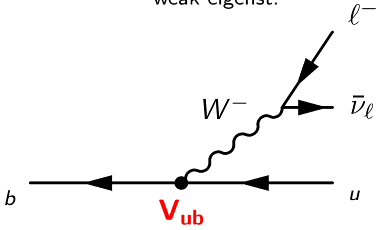

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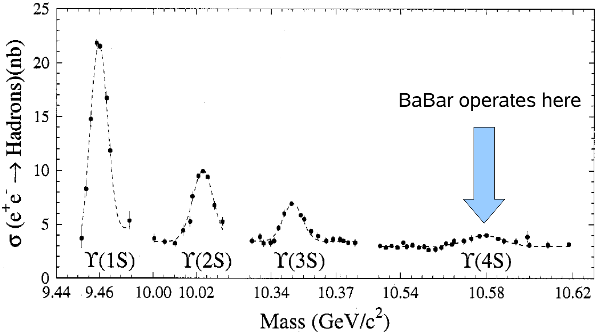
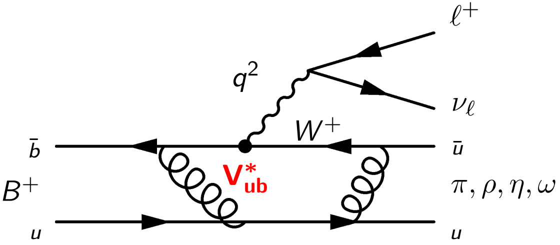
$$e^+e^- \overbrace{\rightarrow}^{\sigma = 1.05\,\text{nb}} \Upsilon(4S) \overbrace{\rightarrow}^{99\%} B\bar{B} = \begin{cases} B^+B^- \ (50\%) \\ B^0\bar{B}^0 \ (50\%) \end{cases}$$



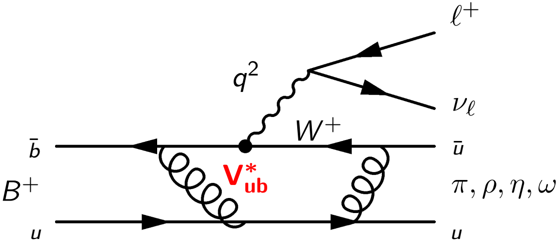
- A lot of $q\bar{q}$ background below the resonance.
- *BABAR*: $\int \mathscr{L}\,dt = 500\,\text{fb}^{-1}$ corresponds to 525 mio. B-Meson-pairs

The Formfactor in B-Meson Decays



Some Theory

- Branching fraction $\propto |V_{ub}|^2$
- u and b quarks not free$\rightarrow \mathcal{B} \propto |V_{ub}|^2 \cdot |f^+(q^2)|^2$
- $f^+(q^2)$ form factor, q^2 transferred 4-momentum
- Different theoretical calculations, here: P. Ball, R. Zwicky 05



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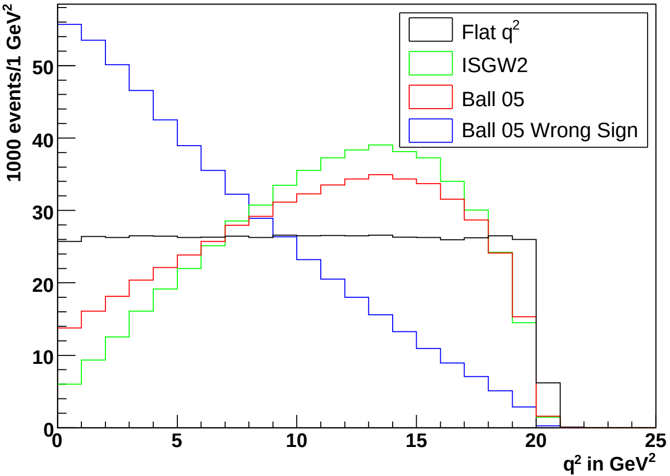
The Formfactor for $B^+ \to \omega \ell^+ \nu_\ell$



Experimental Approach

Methods

- Inclusive measurement $b \to u \ell \nu$
- Exclusive measurement $B \to \pi/\rho/\eta/\omega\ \ell\nu$

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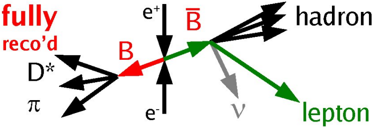
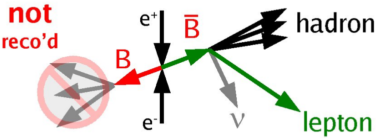


Pro: Cleaner sample
Con: Less statistics

Untagged:



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Experimental Approach

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- Inclusive measurement $b \to u\ell\nu$
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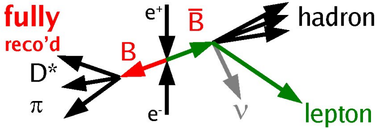

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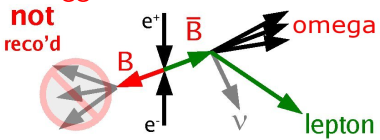

Pro: More statistics
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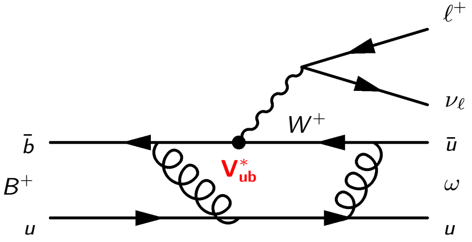
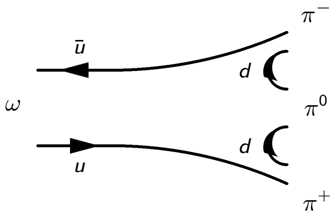
The Decay $B^+ \to \omega \ell^+ \nu_\ell$

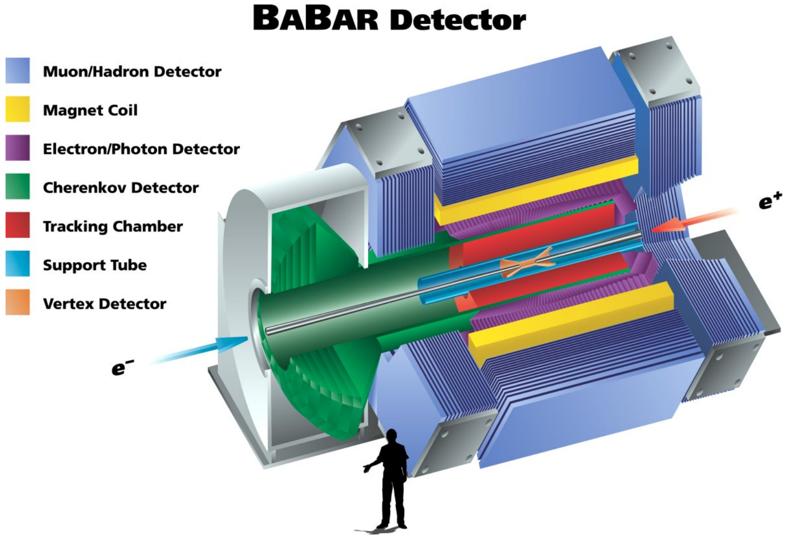
$B^+ \to \omega \ell^+ \nu_\ell$

$\omega \to \pi^+ \pi^- \pi^0$
($\mathcal{B} = 89\%$, PDG06)

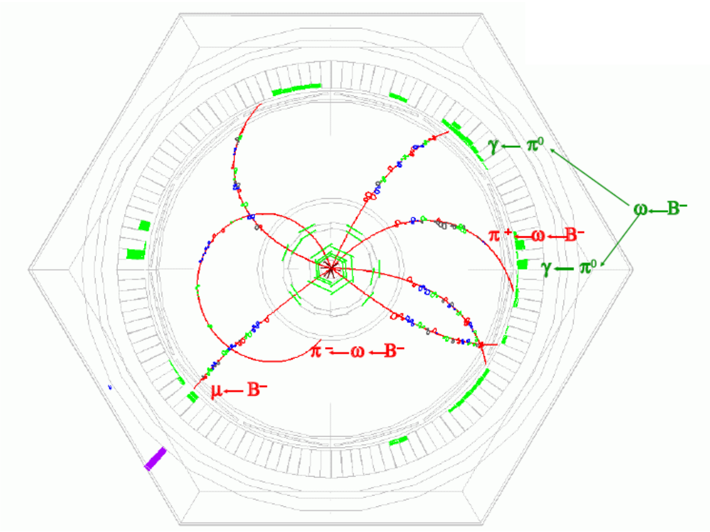




The Detector

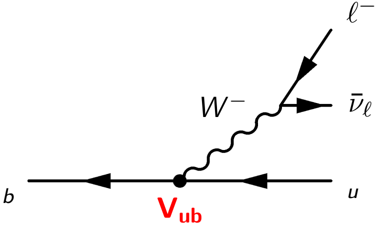


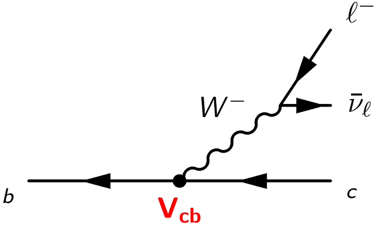
An event $B^- \to \omega\mu^-\bar{\nu}_\mu$



The $c\ell\nu$-Background

Signal	$b \to c\ell\nu$-Background
$B \to \omega\ell\nu \propto \lvert V_{ub}\rvert^2$	e.g. $B \to D^*\ell\nu \propto \lvert V_{cb}\rvert^2$

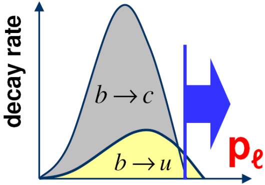




$V_{cb} \approx 10 \cdot V_{ub}$, factor 0.5 from phase space ($m_{D^*} \approx 2\,\mathrm{GeV}$)

$B\,(B \to c\ell\nu) \approx 50 \cdot B\,(B \to \omega\ell\nu)$

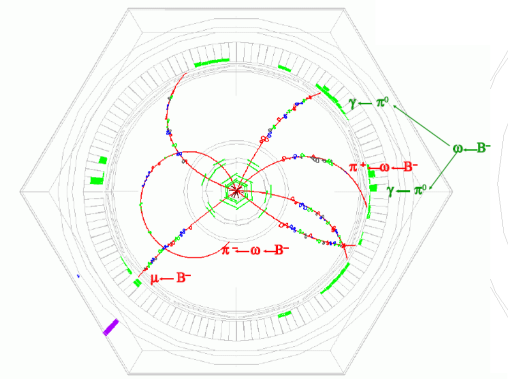
Hard to distinguish $\to$ kinematics p_ℓ^*



The Continuum-Background

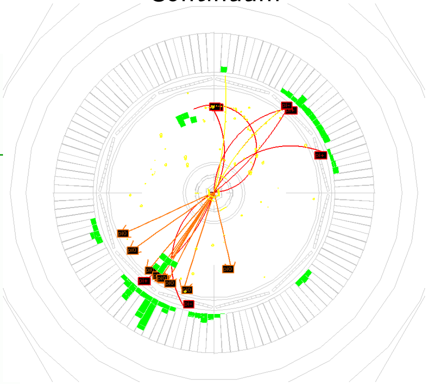
Continuum background = events **not** from $\Upsilon(4S)$
i.e. $e^+e^- \rightarrow u\bar{u},\ d\bar{d},\ s\bar{s},\ c\bar{c}$

Signal



Spherical

Continuum



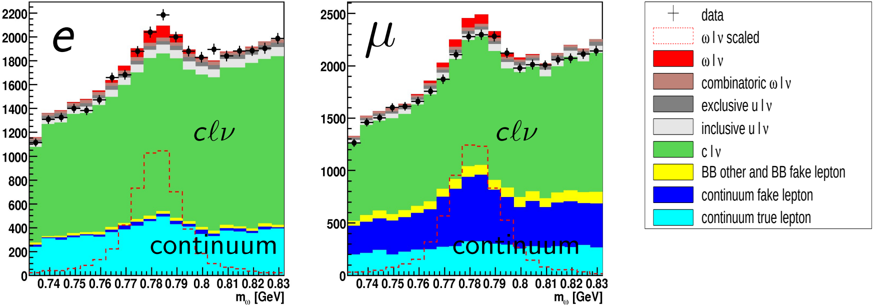
Jet-like

Steps in the Analysis

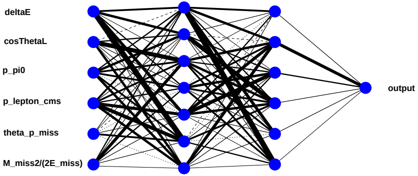
1. Preselection; Reduce the data $1\,\mathrm{Tbytes} \rightarrow 25\,\mathrm{Gbytes}$
2. Selection via Neural Networks (NN)
3. Fit of MC sources to data using a maximum likelihood fit
4. Study of systematic errors

Preselection: Example invariant $\pi^+\pi^-\pi^0$ mass

$732\,\mathrm{MeV} < m_{\pi^+\pi^-\pi^0} < 832\,\mathrm{MeV}$ (remember $m_\omega^{\mathrm{PDG06}} = 783\,\mathrm{MeV}$)



Neural Nets



Neural Nets

- Map different input variables to a single output variable, the discriminant
- Mapping is constructed via the so called training-process
- Can use correlations between input variables $\longrightarrow$ better background suppression

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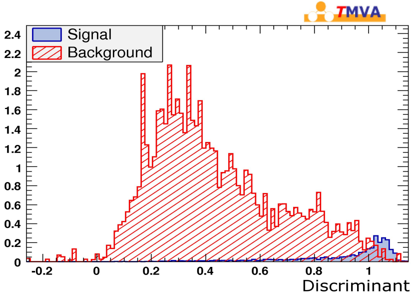
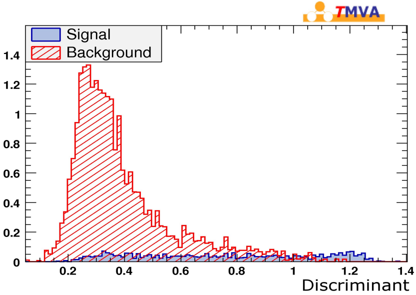
Configuration

- Train 2 Neural Nets on MC simulated events
  1. continuum background ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$)
  2. $c\ell\nu$ background
- 12 inputs, 2 hidden layer, 1 output

Trained against continuum



Trained against $c\ell\nu$



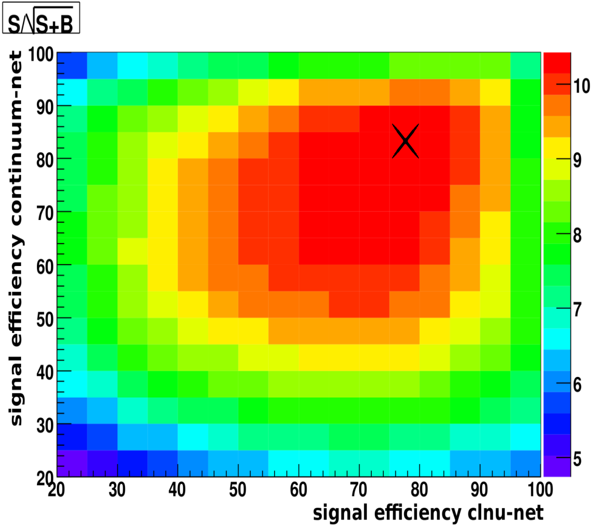
Good background suppression!

But what value (signal efficiency $\epsilon^{\text{sig.}}$) to require?

$\epsilon^{\text{sig.}}$ vs. $\epsilon^{\text{bkg.}}$

Optimization

Optimize statistical error of the analysis → Maximize $S/\sqrt{S+B}$



Result:

Maximal $S/\sqrt{S+B}$ at

$\epsilon^{\text{sig.}}_{\text{continuum}} = 0.80$

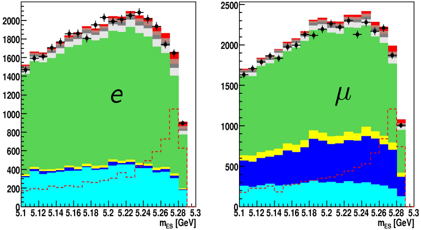
$\epsilon^{\text{bkg.}}_{\text{continuum}} = 0.14$

$\epsilon^{\text{sig.}}_{c\ell\nu} = 0.75$

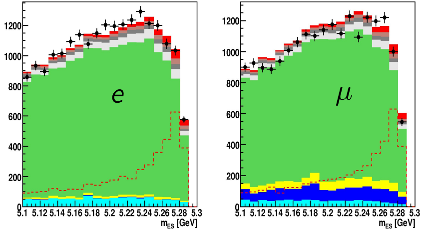
$\epsilon^{\text{bkg.}}_{c\ell\nu} = 0.19$

Neural Net Effect on Inv. B-mass

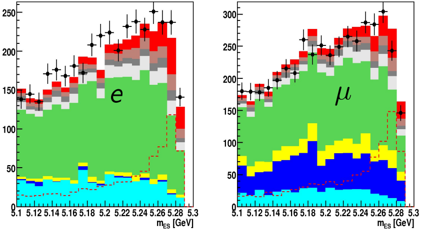
Inv. B-mass before selection with NN

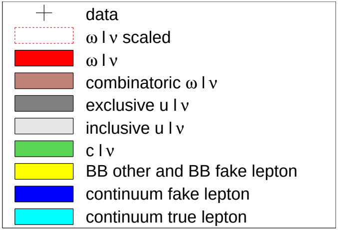


Inv. B-mass after selection with continuum-NN



Inv. B-mass after selection with $c\ell\nu$-NN



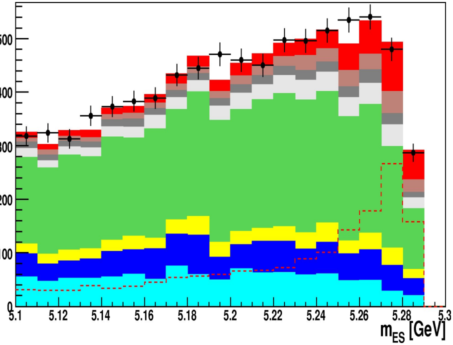


Fit

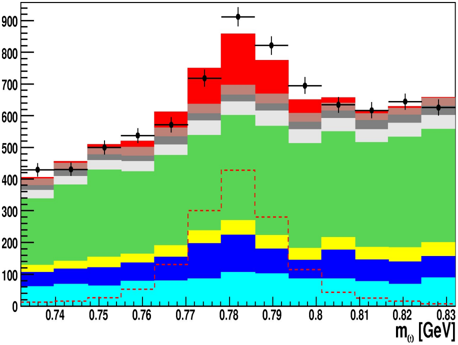
To extract the $\mathcal{B}\left(B^+ \to \omega\ell^+\nu_\ell\right)$ fit MC sources to data.

1. Get scaling factor $f^{\text{sig}}_{\text{scaling}}$ from the fit
2. $\mathcal{B}^{\text{sig}}_{\text{measured}} = \mathcal{B}^{\text{sig}}_{\text{MC}} \cdot f^{\text{sig}}_{\text{scaling}}$

B-mass

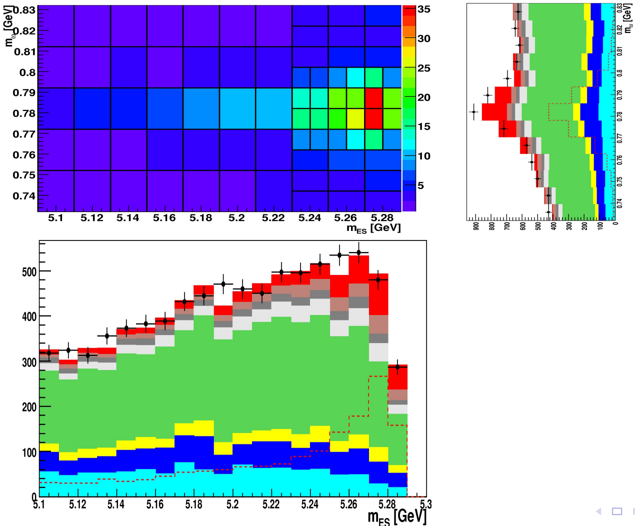


ω-mass



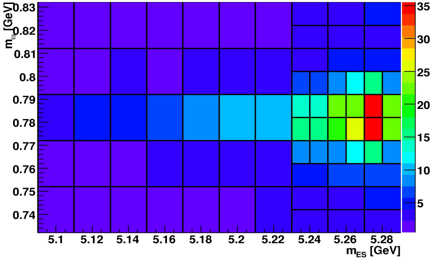
Fit Plane: B-mass/ω-mass

Signal $\omega\ell\nu$-MC

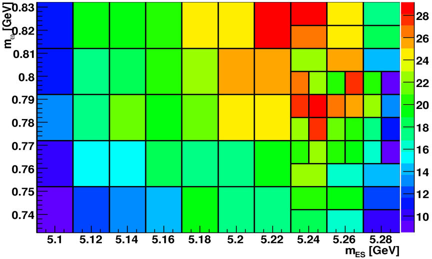


Fit Binning

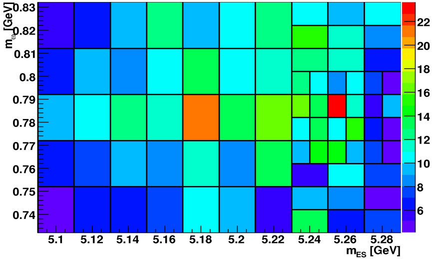
Signal $\omega\ell\nu$-MC



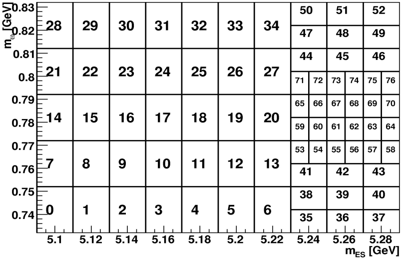
$c\ell\nu$-background-MC



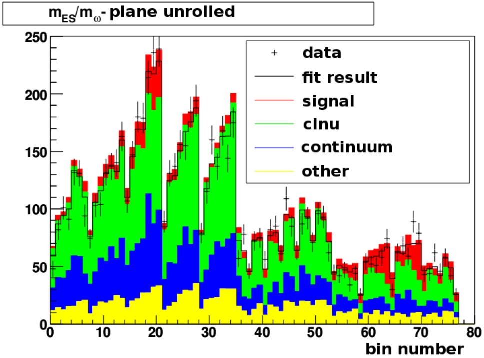
Continuum-background-MC



Binning: 2D-histogram $\rightarrow$ 1D-histogram



- Maximum Likelihood fit (R. Barlow, C. Beeston)
- Float signal and $c\ell\nu$ background
- Fix continuum and other backgrounds



scaling factors:

$f_{c\ell\nu} = 0.90$

$f_{\text{signal}} = 0.92$

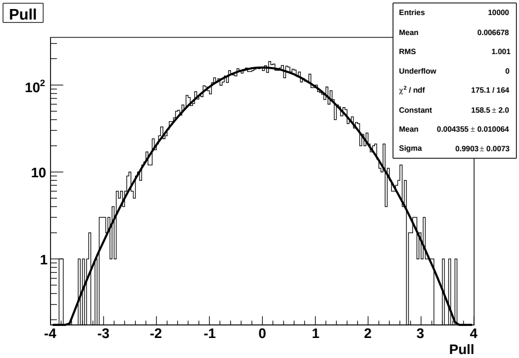
$\downarrow (\mathcal{B}_{\text{MC}}$ known)

$\mathcal{B}\left(B^+ \to \omega\ell^+\nu_\ell\right)$

$= (1.20 \pm 0.14_{\text{stat.}}) \cdot 10^{-4}$

Fit Validation

- Is the fit stable?
- Repeat fit procedure with Toy-MC and look at pull distribution
- pull $= \frac{\mathcal{B}\left(B^+\rightarrow\omega\ell^+\nu_\ell\right)^{\text{measured}} - \mathcal{B}\left(B^+\rightarrow\omega\ell^+\nu_\ell\right)^{\text{MC}}}{\Delta\mathcal{B}(B^+\rightarrow\omega\ell^+\nu_\ell)^{\text{measured}}}$
- Normal distribution expected: mean 0.0, width 1.0



Mean: 0.004 ± 0.010

Sigma: 0.99 ± 0.01

$\rightarrow$ No bias

Systematics

Sources of systematic errors

1. Reconstruction efficiencies
2. Physics modeling
3. Miscellaneous

Systematic Errors

Source of error	Relative error on $\mathcal{B}$ in %
Detector properties and reconstruction	
Track reconstruction	2.5
Photon	2.5
π^0 reconstruction	3.8
Lepton identification	2.1
K_L	4.4
Physics modeling	
Continuum normalization	0.1
$u\ell\nu$ branching fraction	1.8
$c\ell\nu$-MC modeling	8.2
$\omega\ell\nu$ formfactor	2.4
Other	
Training of the NN	5.4
No. of B-mesons	1.3
Multiple candidates	1.2
$\mathcal{B}\left(\omega \to \pi^+\pi^-\pi^0\right)$	0.7
Total	12.6

Systematic Error: $c\ell\nu$-MC modeling

The $c\ell\nu$-MC does not describe our data!
Reason unknown, normalization of the $c\ell\nu$-MC $\approx$ **14% off**
$c\ell\nu$-MC floats in fit $\rightarrow$ Is $c\ell\nu$-MC shape correct?

$c\ell\nu$-scaling factors:

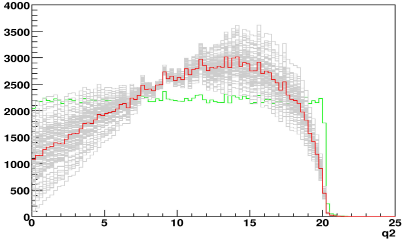
1. 0.86 after preselection
2. 0.88 after continuum-net
3. 0.90 after after both nets

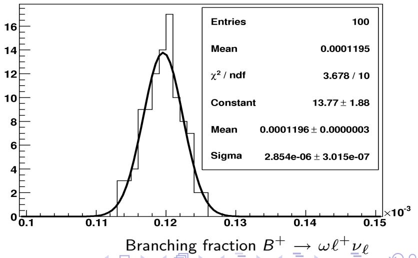
$\rightarrow$ Use scaling factor of 0.86 and fix it in the fit.
$\rightarrow$ Deviation of 8.2%.

Systematic Error: Formfactor Model

1. Vary the parameters of the Formfactor model
2. Repeat the fit
3. Use width of $\mathcal{B}$-distribution as syst. error

$\longrightarrow$ rel. syst. error of 2.4%

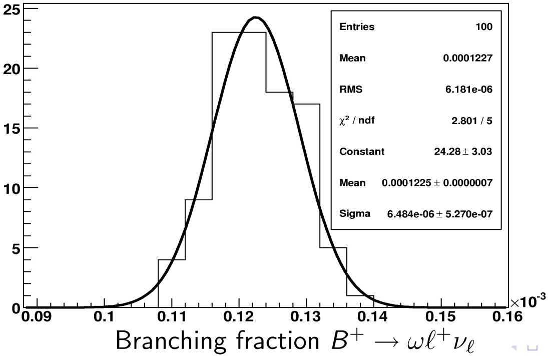




Systematic Error: Neural Net Training

- Random element in NN Training: Random weights at start
- Train 100 pairs of NN
- Repeat fit, use width of $\mathcal{B}$-distribution as syst. error

$\rightarrow$ rel. syst. error of 5.4%



Results

Found 855 ± 10 signal at 6617 ± 58 background-events
Measured branching fraction:

$$\mathcal{B}\left(B^+ \to \omega\ell^+\nu_\ell\right) = (1.20 \pm 0.14_{\text{stat.}} \pm 0.15_{\text{syst.}}) \cdot 10^{-4}$$
$$= (1.20 \pm 0.21_{\text{tot.}}) \cdot 10^{-4}$$

Well in agreement with PDG06:

$$\mathcal{B}\left(B^+ \to \omega\ell^+\nu_\ell\right) = (1.3 \pm 0.6_{\text{tot.}}) \cdot 10^{-4}$$

And preliminary Belle (HFAG):

$$\mathcal{B}\left(B^+ \to \omega\ell^+\nu_\ell\right) = (1.17 \pm 0.39_{\text{stat.}} \pm 0.11_{\text{syst.}}) \cdot 10^{-4}$$
$$= (1.17 \pm 0.41_{\text{tot.}}) \cdot 10^{-4}$$

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$$= \left(1.17 \pm 0.41_{\text{tot.}}\right) \cdot 10^{-4}$$

Outlook

1. Currently the study is repeated
2. Some improvements:
   - Less neurons to reduce error due to training
   - Different NN optimization: S/B $\longrightarrow$ harder cut against $c\ell\nu$-background
3. Prepare analysis note for publication