

# Charmless Semileptonic $B$ Decays at Belle

1.  $B \rightarrow \eta^{(\prime)} \ell \nu_\ell$

2.  $B \rightarrow \pi \tau \nu_\tau$

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On behalf of the Belle Collaboration.

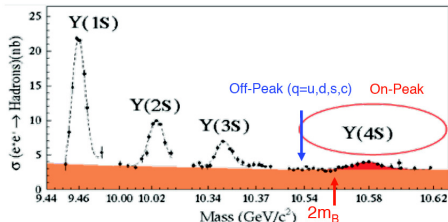


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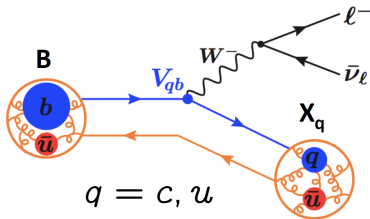
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# Introduction and Motivation

- Beam energies at B-Factories tuned to produce B pairs through  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ .
- $\mathcal{B}(\Upsilon(4S) \rightarrow B\bar{B}) \approx 96\%$ .
- Semileptonic B decays used to extract CKM matrix elements  $|V_{cb}|$ ,  $|V_{ub}|$

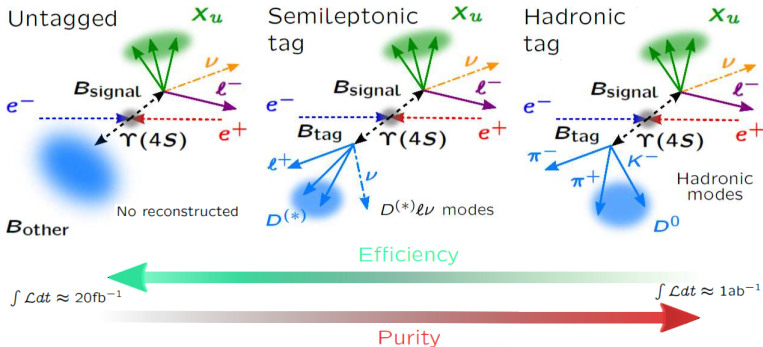


- Two approaches to measure semileptonic B decays:
  - ▶ Exclusive: a specific final state is reconstructed (e.g.  $B \rightarrow \pi l \nu$ )
  - ▶ Inclusive: All  $B \rightarrow X_q l \nu$  final states within a region of phase space are reconstructed.
- $\sim 3\sigma$  discrepancy between inclusive and exclusive measurements.



# Reconstruction of the decay

Methods to reconstruct  $B$  mesons:

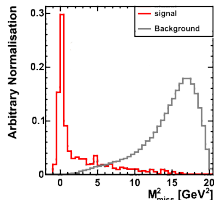


Signal Side:

- Identify a lepton.
- Meson reconstructed w FSP:  $\pi^\pm, \pi^0, \gamma$ .
- Neutrino is inferred from

$$P_{\text{miss}} = P_{\gamma(4S)} - P_{B_{\text{tag}}} - P_{\ell^+} - P_{X_u}$$

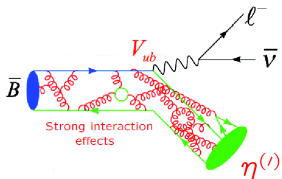
$$\text{Fit variable: } M_{\text{miss}}^2 = |P_{\text{miss}}|^2$$



# Exclusive $B^- \rightarrow \eta^{(\prime)} \ell^- \bar{\nu}_\ell$ decay

- Reconstructed channels:

- ▶  $\eta \rightarrow \gamma\gamma$  BF:  $(39.31 \pm 0.20)\%$
- ▶  $\eta \rightarrow \pi^+\pi^-\pi^0$  BF:  $(22.74 \pm 0.28)\%$
- ▶  $\eta' \rightarrow \eta\gamma\gamma\pi^+\pi^-$  BF:  $(16.9 \pm 0.3)\%$

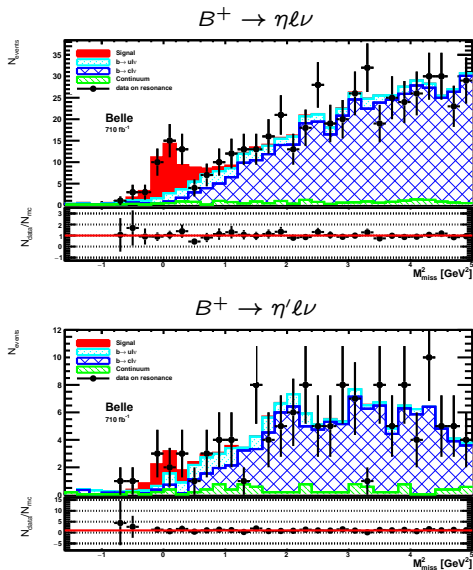


Decay rate:

$$\frac{d\Gamma(B \rightarrow \eta^{(\prime)} \ell \bar{\nu})}{dq^2} \sim |V_{ub}|^2 |f_+(q^2)|^2$$
$$q^2 = (P_\ell + P_\nu)^2$$

- Form factor  $f_+(q^2)$  calculation represents a theoretical challenge.
- The signal  $B^- \rightarrow \eta^{(\prime)} \ell^- \bar{\nu}_\ell$  is generated using ISGW2 model.
- $|V_{ub}|$  measurement from this channel not possible yet since a reliable  $f_+(q^2)$  is needed.

# Hadronic tag $B \rightarrow \eta \ell \nu$ and $B \rightarrow \eta' \ell \nu$ yields



Cut based analysis.

Full  $\Upsilon(4S)$  dataset  $710\text{fb}^{-1}$

Yields extracted using an extended binned maximum likelihood on the  $M_{\text{miss}}^2$ .

Components:

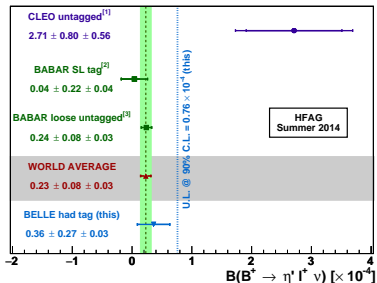
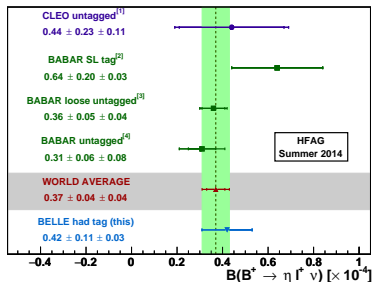
Signal  
 other  $B \rightarrow X_{u\ell\nu}$   
 $B \rightarrow X_{c\ell\nu}$   
 $e^+e^- \rightarrow q\bar{q}$  (fixed)

Signal Yields  $\pm$  stats (Full reco at Belle)

Channel	This	$\chi^2/NDF$
$B \rightarrow \eta \ell \nu$	$38.8 \pm 10.1$	18.0/29
$B \rightarrow \eta' \ell \nu$	$5.7 \pm 4.4$	24.4/29

# Branching ratio and previous measurements

A comparison of this result with previous branching ratio measurements is shown below



1. PRD76 012007 (2007)
2. PRD79 052011 (2008)
3. PRL 101 081801 (2008)
4. PRD83 052011 (2011)

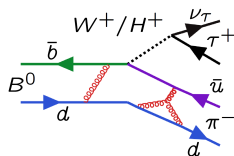
Total Systematic Uncertainties (This)  
 $B \rightarrow \eta l \nu$  6.4%  
 $B \rightarrow \eta' l \nu$  8.3%

Small background results in better control on systematics  
Most precise measurements from tag method

# Exclusive $B^0 \rightarrow \pi^- \tau^+ \nu_\tau$ decay

- Reconstructed channels:

- $\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$  BF:  $(17.83 \pm 0.04)\%$
- $\tau^- \rightarrow \pi^- \nu_\tau$  BF:  $(10.83 \pm 0.06)\%$
- $\tau^- \rightarrow \rho^- \nu_\tau$  BF:  $(25.52 \pm 0.09)\%$



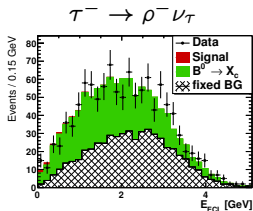
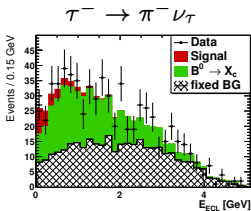
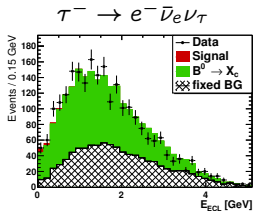
Decay rate:

$$\frac{d\Gamma(B \rightarrow \pi\tau\nu)}{dq^2} \sim F(|V_{ub}|^2, |f_+(q^2)|^2, |f_0(q^2)|^2)$$

$|f_0(q^2)|^2$  appears due to non-negligible  $m_\tau$ .

- In new physics models e.g. 2HDM, this process is mediated by  $H^+$
- $R(\pi) = \mathcal{B}(B \rightarrow \pi\tau\nu_\tau)/\mathcal{B}(B \rightarrow \pi\ell\nu_\ell)$  depends on  $f_0(q^2)/f_+(q^2)$ .
- In SM  $R(\pi) = 0.641(17)$ ,  $\Rightarrow \mathcal{B}(B \rightarrow \pi\tau\nu_\tau) = 9.35(38) \times 10^{-5}$   
LQCD, FNAL/MILC arXiv:1510.02349 [hep-ph]

# Hadronic tag $B^0 \rightarrow \pi^- \tau^+ \nu_\tau$ yields



Components:

Signal

$B \rightarrow X_c \ell \nu$

Other (fixed)

Multivariate analysis (BDT).

Full  $\Upsilon(4S)$  dataset  $710\text{fb}^{-1}$

Yields extracted using an extended binned maximum likelihood on the  $E_{\text{ECL}}$ .

$E_{\text{ECL}}$ : extra energy deposited in Electromagnetic Calorimeter.

First experimental result on this decay, published PRD93 032007 (2016).

Combined signal yield:  $52 \pm 24$

$\mathcal{B}(B^0 \rightarrow \pi^- \tau^+ \nu_\tau) = (1.52 \pm 0.74 \pm 0.13) \times 10^{-4}$

Significance:  $2.4\sigma$  (with systematics)

U.L. :  $\mathcal{B}(B^0 \rightarrow \pi^- \tau^+ \nu_\tau) < 2.5 \times 10^{-4}$  @90% C.L.



# Summary and outlook

## $B \rightarrow \eta^{(\prime)} \ell \nu$

- We have measured the branching ratio for  $B \rightarrow \eta \ell \nu$  to be  $(0.42 \pm 0.11_{\text{stat}} \pm 0.03_{\text{syst}}) \times 10^{-4}$ .
- We set an upper limit at 90% to the branching ratio for  $B \rightarrow \eta' \ell \nu$  of  $0.76 \times 10^{-4}$ .
- Systematics uncertainties from hadronic tag are smaller than in other  $B$  meson reconstruction techniques.
- With better prediction of form factors for  $B \rightarrow \eta \ell \nu$ , a measurement of  $|V_{ub}|$  would be feasible.

## $B \rightarrow \pi \tau \nu$

- First experimental result on this decay.
- The upper limit  $\mathcal{B}(B^0 \rightarrow \pi^- \tau^+ \nu_\tau) < 2.5 \times 10^{-4}$  is compatible with SM.

Thank you !!!

# Backup Slides

# Summary Systematics for $B^- \rightarrow \eta^{(i)} \ell^- \bar{\nu}_\ell$ in percent.

Systematic	$B \rightarrow \eta \ell \nu$	$B \rightarrow \eta' \ell \nu$
Continuum	0.47	3.9
Secondary leptons	0.03	0.0
Fake leptons	0.47	1.8
$b \rightarrow u \ell \nu$ BF	0.50	2.4
$b \rightarrow c \ell \nu$ BF	0.13	0.62
$b \rightarrow u \ell \nu$ FF	0.31	0.56
$b \rightarrow c \ell \nu$ FF	1.1	0.23
<b>Signal model</b>	<b>0.88</b>	<b>0.28</b>
$\pi$ ID	0.41	2.9
$\ell$ ID	2.1	1.6
$\pi^0$ eff	2.5	0.0
$\gamma$ eff	3.1	4.0
track eff	0.5	1.05
Btag eff	4.2	4.2
BF( $\eta \rightarrow$ )	0.5	1.7
total	6.4	8.3

# Summary Systematics for $B^0 \rightarrow \pi^- \tau^+ \nu_\tau$ in percent.

Systematic	$B \rightarrow \pi \tau \nu$
Particle ID	2.4
Track efficiencys	0.7
$N(B\bar{B})$	1.4
$K_L$ veto	3.2
Background BF	2.8
Tag side	4.6
$V_{ub}$	2.8
Signal model	1.8
Rare processes	2.0
$B \rightarrow X_u \tau \nu$	2.2
Background fit	0.2
total	8.3

## Belle Detector

