New Results from Belle

Rencontres de Moriond EW 2013

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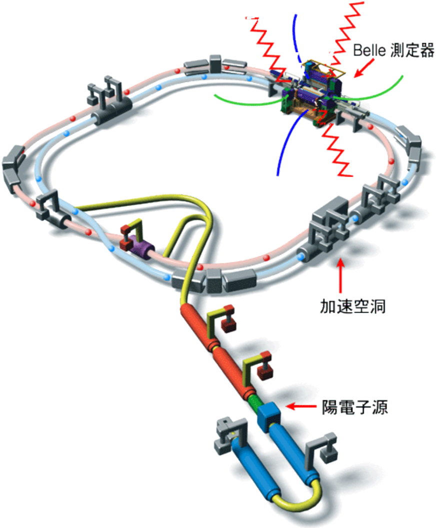
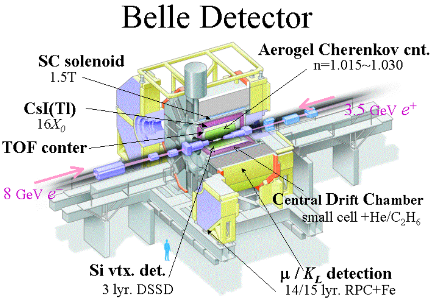


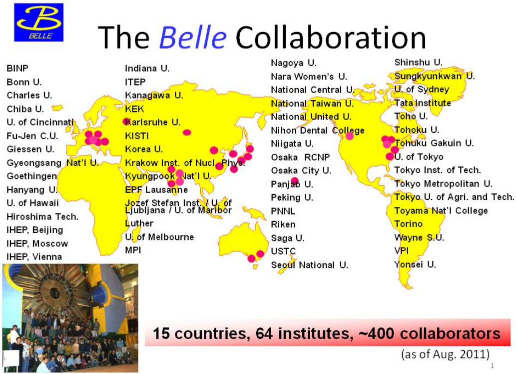
The Belle Detector



- located at the asymmetric e^+e^- collider KEKB (Japan)
- designed for time-dependent CPV
- works well as 4π multi-purpose detector
- data taking until 2010
- upgrade to Belle II at SuperKEKB (2015 / 2016)

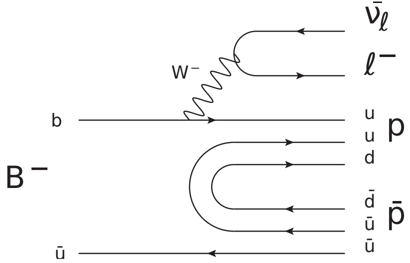
The Belle Dataset

- world's largest integrated luminosity ($\approx 1\text{ab}^{-1}$)
- $\Upsilon(4S)$ dataset ($b\bar{b}$) with ≈ 772 million $B\bar{B}$ pairs
- clean environment
- simple two-body decays $\Rightarrow$ strong kinematic constraints



$B^- \to p\bar{p}\ell^-\bar{\nu}_\ell$

- basic idea: measurement of $|V_{ub}|$ of the CKM matrix
- previous efforts center around $B \to M\ell\nu$ (M is a charmless meson)
- no observation of semileptonic charmless baryon anti-baryon B decay
- existing upper limit: $\mathcal{B}(B^- \to p\bar{p}e^-\bar{\nu}_e) < 5.2\times10^{-3}$ (CLEO)



Motivation

previously: SM estimation[1] $\mathcal{O}(10^{-5} - 10^{-6})$
2011: theoretical paper[2] predicted
$\mathcal{B}(B^- \to p\bar{p}\ell^-\bar{\nu}_\ell) = (1.04 \pm 0.38) \times 10^{-4}$

- in reach of Belle dataset
- **support:** enable many similar channels in the $|V_{ub}|$ measurement
- **falsify:** could enhance theoretical understanding of baryonic B decays

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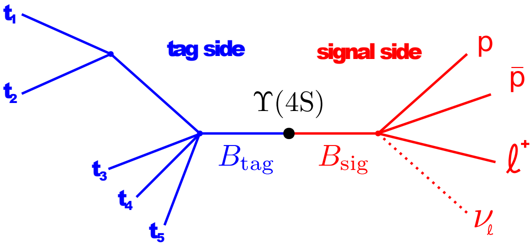
1 W.-S. Hou and A. Soni, PRL 86, 4247 (2001)
2 C.Q. Geng and Y.K. Hsiao, Phys. Lett. B 704, 495 (2011)

Reconstruction

Problem: low signal expectancy, invisible neutrinos

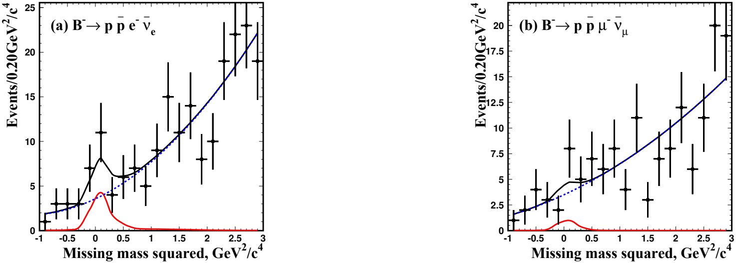
Solution: full reconstruction tagging



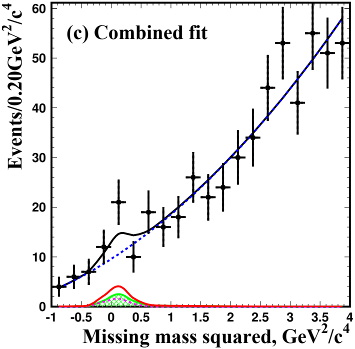
$$M^2_{\text{miss}} = [p(\text{Beam}) - (p(B_{\text{tag}}) + p(\text{visible}))]^2$$

Fit Model

- one dimension: M^2_{miss}
- two datasets: $p\bar{p}e$ and $p\bar{p}\mu$
- extended unbinned maximum likelihood fit
- signal: three Gaussian functions, fixed shape
- background: second order Chebyshev polynomial, floating shape



Results



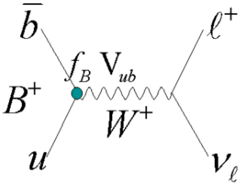
signal significance: 3.19σ

Mode	$\mathcal{B}(10^{-6})$	U.L. (10^{-6})
$B^- \to p\bar{p}e^-\bar{\nu}_e$	$8.22^{+3.74}_{-3.20} \pm 0.55$	13.8
$B^- \to p\bar{p}\mu^-\bar{\nu}_\mu$	$3.13^{+3.10}_{-2.40} \pm 0.71$	8.5
Combined Fit	$5.78^{+2.42}_{-2.13} \pm 0.86$	9.6

Measurement of $B^- \to \tau\bar{\nu}_\tau$

$$\Gamma(B^+ \to \ell^+\nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- helicity-suppressed:
  $\Gamma(B^+ \to e^+\nu_e) \ll \Gamma(B^+ \to \mu^+\nu_\mu) \ll$
  $\Gamma(B^+ \to \tau^+\nu_\tau)$
- very clean place to measure f_B (or V_{ub}?)
  and/or search for new physics (e.g. H^+, LQ)
- charged boson may take the role of the W



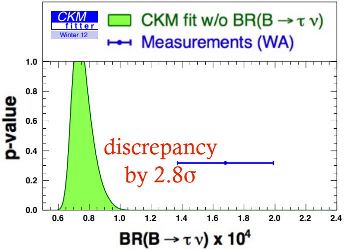
(a)

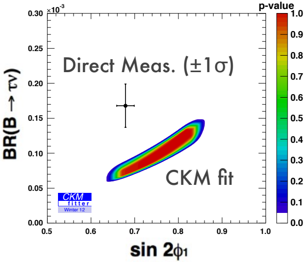
Charged Higgs Contributions

- e.g. H^+ of 2-Higgs doublet model (type II)[3]:

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = \mathcal{B}_{\rm SM}(B^+ \to \tau^+\nu_\tau) \times r_H$$

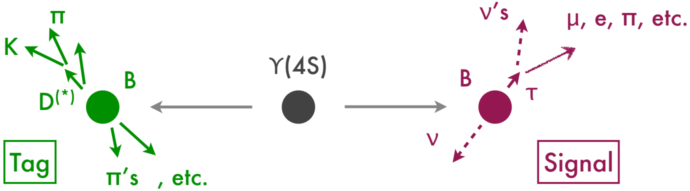
$$r_H = \left[1 - (m_B^2/m_H^2)\tan^2\beta\right]^2$$



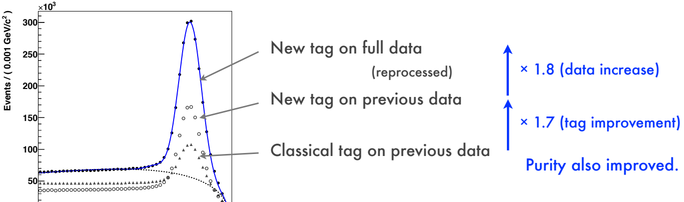


3 W.S. Hou, PRD 48, 2342 (1993)

Reconstruction



- 2-3 neutrinos in the final state
- full reconstruction tagging (hadronic)

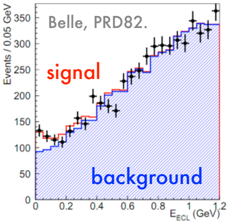


×3 B_{tag} sample size

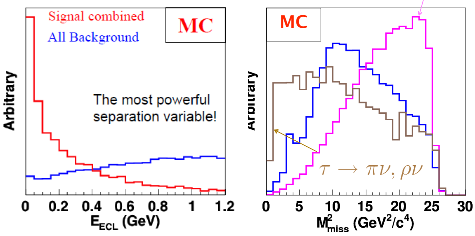
Signal Extraction

- Signal τ modes: $\tau^+ \to e^+\nu_e\overline{\nu}_\tau,\ \mu^+\nu_\mu\overline{\nu}_\tau,\ \pi^+\overline{\nu}_\tau,\ \rho^+\overline{\nu}_\tau$
- 2D fitting to $E_{\rm ECL}$ & $M^2_{\rm miss}$
  - improve sensitivity by $\sim 20\%$
  - more robust against peaking backgrounds in $E_{\rm ECL}$

previous analyses
($E_{\rm ECL}$ only)

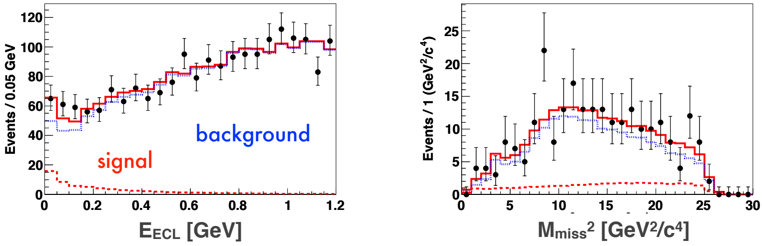


■ *The fitting variables*



Results

- Simultaneous fit to different τ decay modes
  Figures below shown for the sum of different τ decay modes



(Projection for all M_{miss}^2 region.)

(Projection for E_{ECL} < 0.2 GeV)

- Signal yield: $62^{+23}_{-22} \pm 6$ significance = 3.0σ incl. systematic error
- $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \left(0.72^{+0.27}_{-0.25} \pm 0.11\right) \times 10^{-4}$ arXiv:1208.4678, *to appear in PRL*

Results

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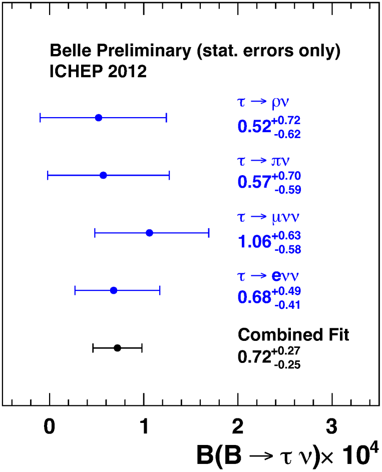
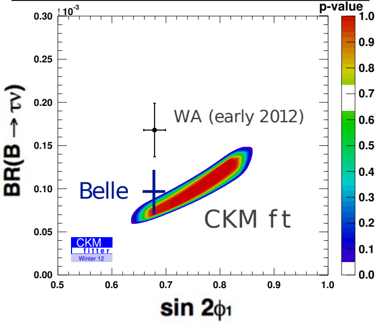
- consistency over all τ decay modes

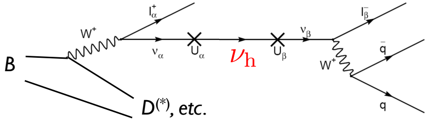


Sub-mode	N_{sig}	(10^{-4})	$B\ (10^{-4})$
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	16^{+11}_{-9}	3.0	$0.68^{+0.49}_{-0.41}$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	26^{+15}_{-14}	3.1	$1.06^{+0.63}_{-0.58}$
$\tau^- \to \pi^- \nu_\tau$	8^{+10}_{-8}	1.8	$0.57^{+0.70}_{-0.59}$
$\tau^- \to \pi^- \pi^0 \nu_\tau$	14^{+19}_{-16}	3.4	$0.52^{+0.72}_{-0.62}$
Combined	62^{+23}_{-22}	11.2	$0.72^{+0.27}_{-0.25}$



Search for Heavy Neutrinos

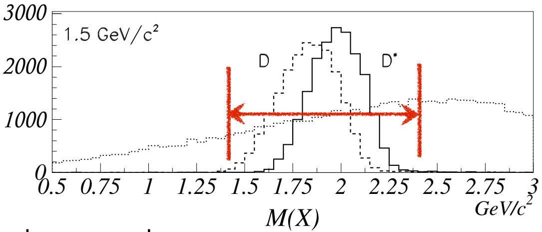
- SM neutrinos strictly massless
- oscillations observed $\Rightarrow$ nonzero masses
- right-handed, heavy neutrinos introduced in BSM models (SUSY, GUT, νMSM)



- search in $B \to X\ell_2^+\nu_h$ with $\nu_h \to l_1^\pm\pi^\mp$
- ν_h interacts only via mixing with ν_L
- long flight distance $\mathcal{O}(20\,\mathrm{m}) \Rightarrow$ low efficiency

Selection

- separately for large and small $M(\nu_\mathrm{h})$
  * "small" $M(\nu_\mathrm{h}) < 2.0\ \mathrm{GeV/c^2}$: $X = D,\ D^*$ only
    $D^{(*)}$ is identified by "missing mass": $M_X^2 \equiv (E_\mathrm{CM} - E_{\ell_1\ell_2\pi})^2 - P_{\ell_1\ell_2\pi}^2 - P_B^2$
  * "large" $M(\nu_\mathrm{h}) \geq 2.0\ \mathrm{GeV/c^2}$: $X = D^{(*)}$, light meson, "nothing"

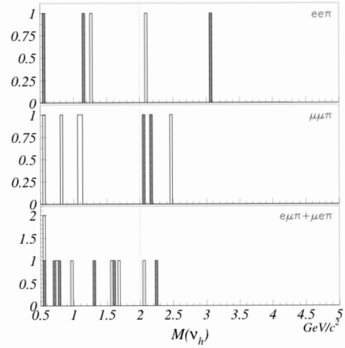


- background suppression:
  * QED: $N(\mathrm{track}) \geq 5$
  * "V" decays from K_S^0, γ, Λ: strict lepton ID and kinematic cuts
  * long flight distance of ν_h is exploited by vertex distance cuts
  * overall background reduction $\mathcal{O}(10^6)$ with $3 - 10\%$ signal efficiency

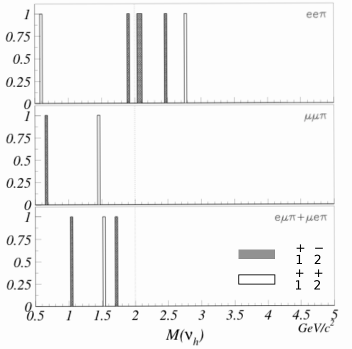
Results

mode	MC expected	Data
$e e \pi$	1.7 ± 0.7	6 ± 2.4
$\mu \mu \pi$	2.3 ± 0.9	2 ± 1.4
$e \mu \pi + \mu e \pi$	4.0 ± 1.2	3 ± 1.7

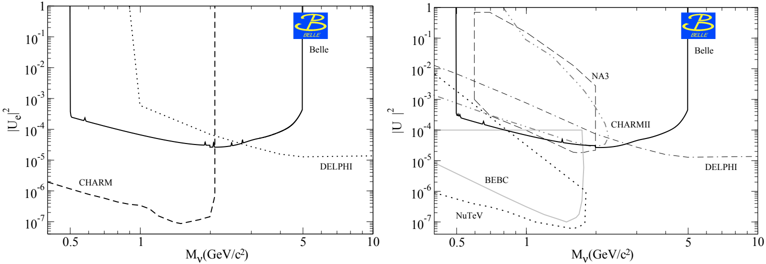
MC (based on 3 "streams")



Data



Upper Limits



- upper limits on $\nu_\mathrm{h} - \nu_\ell$ mixing ($|U_\ell|^2$) are obtained, in the range $0.5 < M(\nu_\mathrm{h}) < 5\ \mathrm{GeV/c^2}$.
  maximum sensitivity is reached at $M(\nu_\mathrm{h}) \sim 2\ \mathrm{GeV/c^2}$.
- upper limit for product branching fraction (for $M(\nu_\mathrm{h}) = 2\ \mathrm{GeV/c^2}$):
  $\mathcal{B}(B \to \ell_2 \nu_\mathrm{h}(X)) \times \mathcal{B}(\nu_\mathrm{h} \to \ell_1 \pi) < 7.5 \times 10^{-7}$ for $\ell = e,\ \mu$

Summary

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$B^- \to p\bar{p}\ell^-\bar{\nu}_\ell$

- first evidence
- upper limits clearly contradictory to prediction

$B^+ \to \tau^+\nu_\tau$

- first evidence
- closer to SM

heavy neutrino search

- UL only

B **factories**

- nice flavor physics going on at the LHC, but B-factories still matter
- plenty of interesting stuff for Belle II