Recent results from heavy flavour experiments

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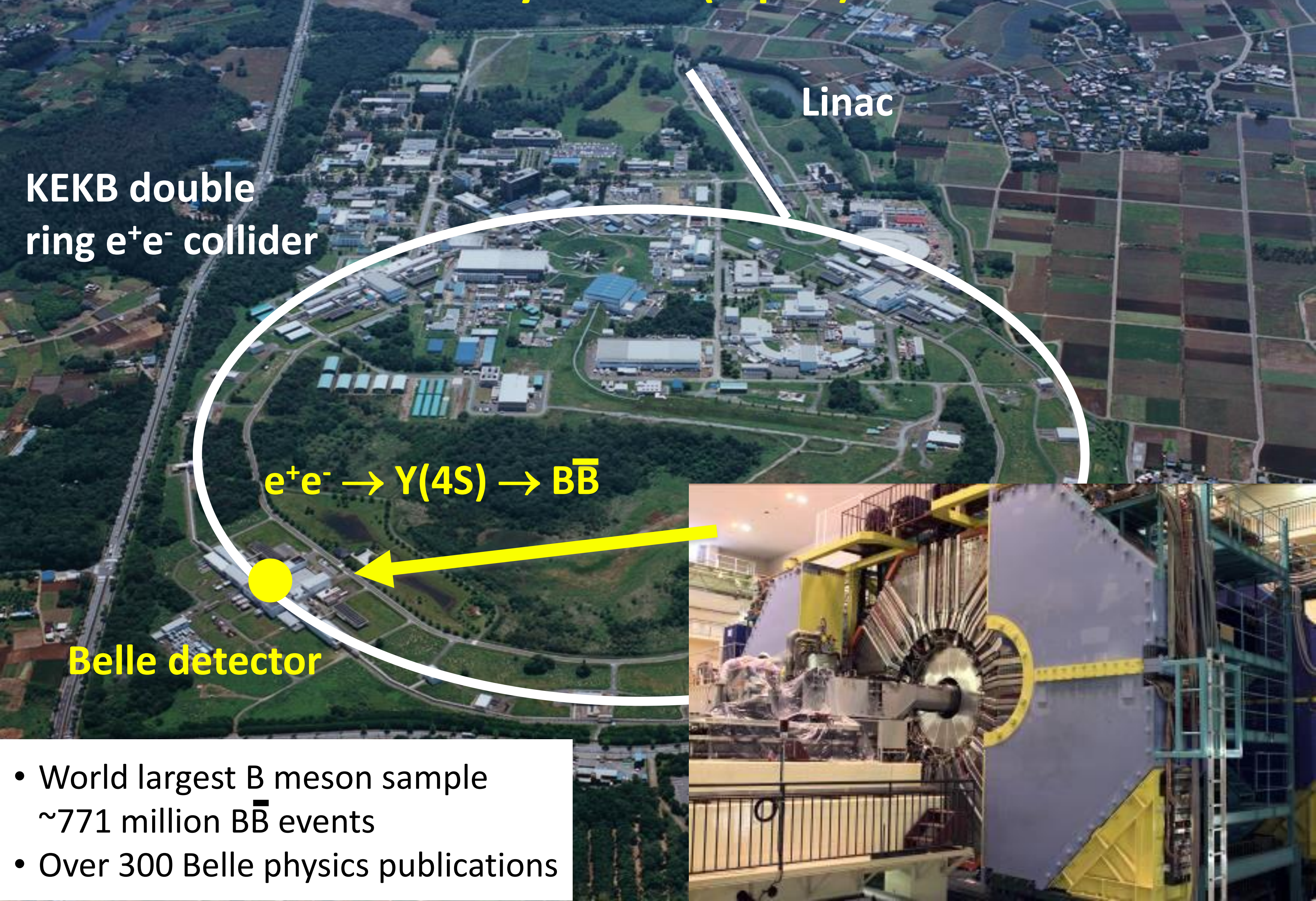
Outline of this talk

- Semileptonic B decays (with a light lepton)
  - Determination of the Cabibbo-Kobayashi-Maskawa matrix elements $|V_{cb}|$ and $|V_{ub}|$
  - Right-handed currents at loop level
- Semileptonic/leptonic B decays involving a τ lepton
  - Scalar charged currents
- $B_{(s)} \to l^+l^-$
  - Higgs-mediated flavor changing neutral currents

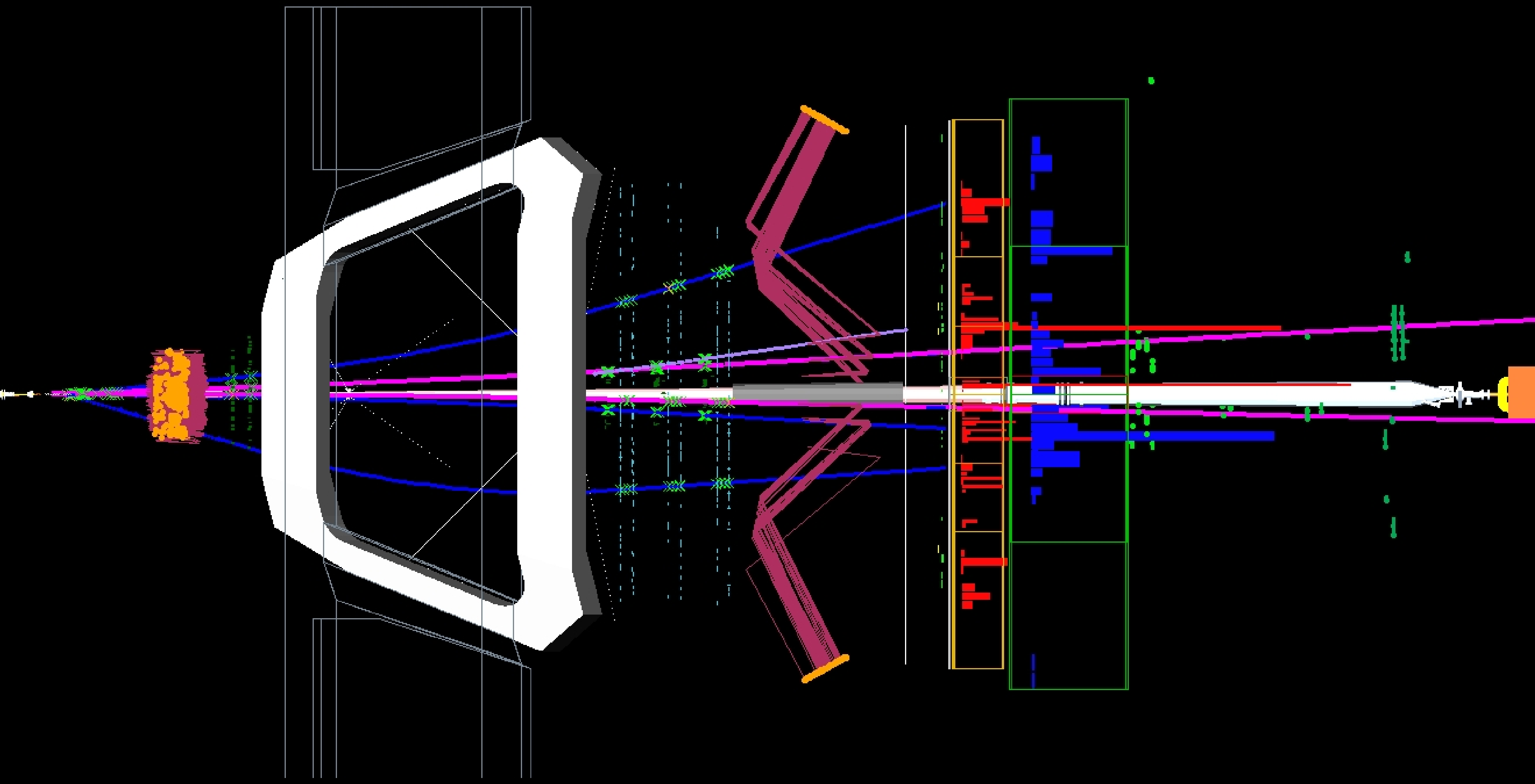
1999 – 2010: B factory at KEK (Japan)



- World largest B meson sample ~771 million $B\bar{B}$ events
- Over 300 Belle physics publications

LHCb analysis

1.0fb^{-1} (2011) + 1.1fb^{-1} (2012)

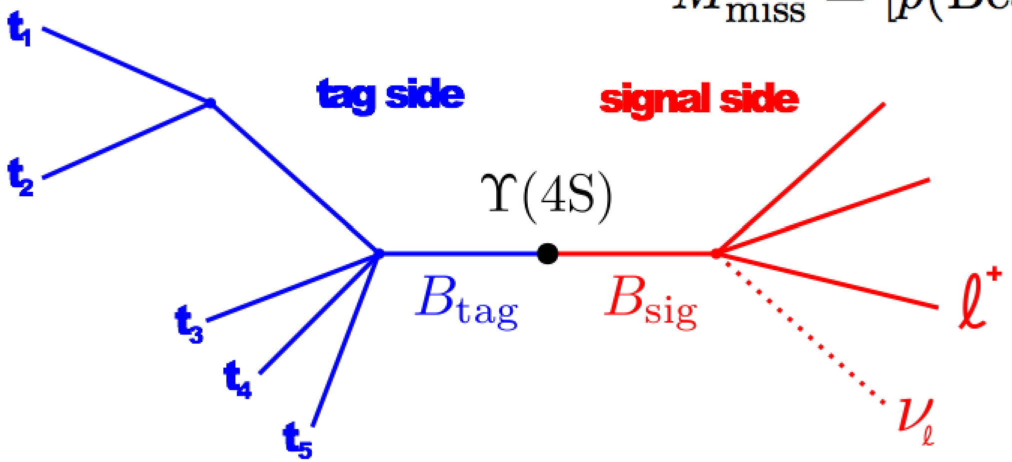


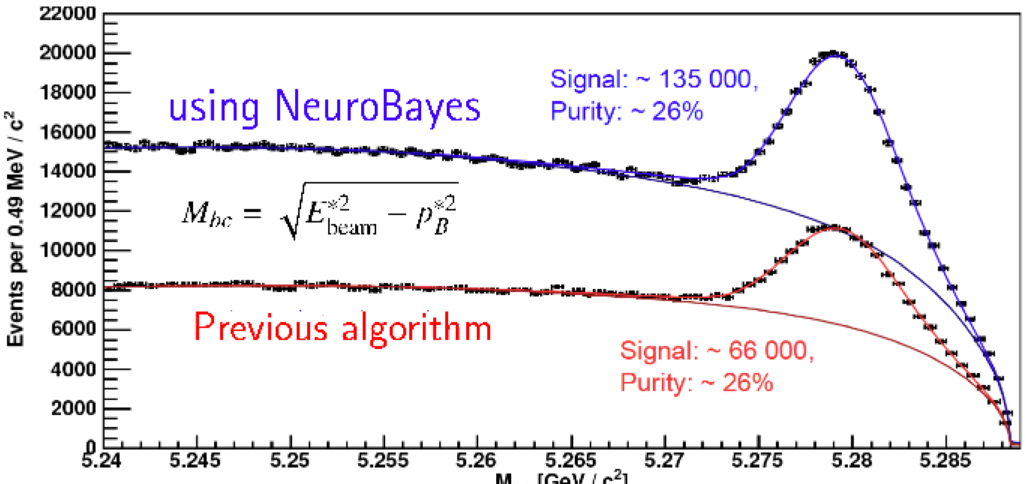
One of the best signal candidates in the 2012 dataset

BDT=0.826 and $m_{\mu\mu}$ = 5353 MeV/c^2

New Belle hadronic tag

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





Michael Feindt (2011)

- New hadronic tag based on Neurobayes
- 2-3x statistical gain over previous analyses

Semileptonic B decays

$|V_{cb}|$ from exclusive decays

$$w = \frac{P_B \cdot P_{D^{(*)}}}{m_B m_{D^{(*)}}} = \frac{m_B^2 + m_{D^{(*)}}^2 - q^2}{2 m_B m_{D^{(*)}}}$$

B → D*lν

$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3} (m_B - m_{D^*})^2 \sqrt{w^2 - 1}\, \chi(w) \mathcal{F}^2(w) |V_{cb}|^2$$

B → Dlν

$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_D^3}{48\pi^3} (m_B + m_D)^2 (w^2 - 1)^{3/2} \mathcal{G}^2(w) |V_{cb}|^2$$

- Theory input: Form factors F(1) and G(1) at zero recoil (w=1) from lattice QCD calculations
- Experimental method: Measure the differential width dΓ as a function of w and extrapolate to zero recoil (typically assuming a parameterization of the form factors)

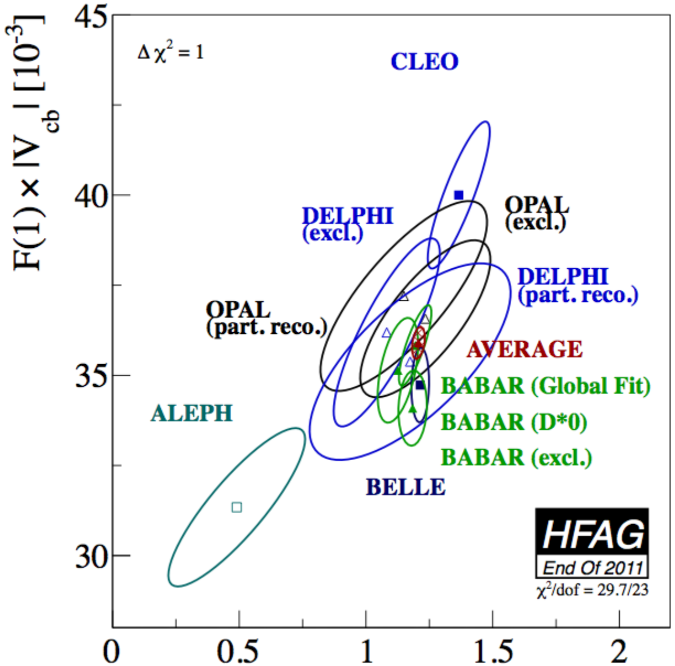
$|V_{cb}|$ from inclusive decays

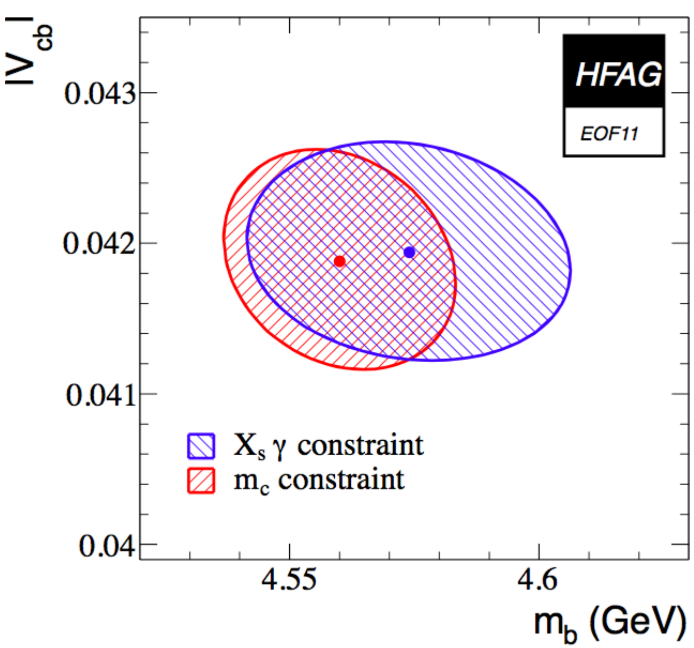
$B \to Xl\nu$

$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2 (1 + \frac{c_5(\mu)\,\langle O_5\rangle(\mu)}{m_b^2} + \frac{c_6(\mu)\,\langle O_6\rangle(\mu)}{m_b^3} + \mathcal{O}(\frac{1}{m_b^4}))$$

- Based on the Operator Product Expansion (OPE)
- $<O_i>$: hadronic matrix elements (non-perturbative)
  c_i: coefficients (perturbative)
- Parton-hadron duality → the hadronic ME depend only on the initial state
- We can determine the hadronic ME from other observables in inclusive B decays (moments of E_l and M^2_X) → global fit

	Kinetic scheme [JHEP 1109 (2011) 055]	1S scheme [PRD70, 094017 (2004)]
O(1)	m_b, m_c	m_b
$O(1/m^2_b)$	μ^2_π, μ^2_G	λ_1, λ_2
$O(1/m^3_b)$	ρ^3_D, ρ^3_{LS}	ρ_1, τ_{1-3}





$|V_{cb}|$

Exclusive ($D^* l \nu$)

$|V_{cb}| = (39.54 +/- 0.50_{exp} +/- 0.74_{th}) \times 10^{-3}$

Inclusive (kinetic)

$|V_{cb}| = (41.88 +/- 0.73) \times 10^{-3}$

HFAG preprint [arXiv:1207.1158]

- Exclusive and inclusive agree at the level of ~2 sigma

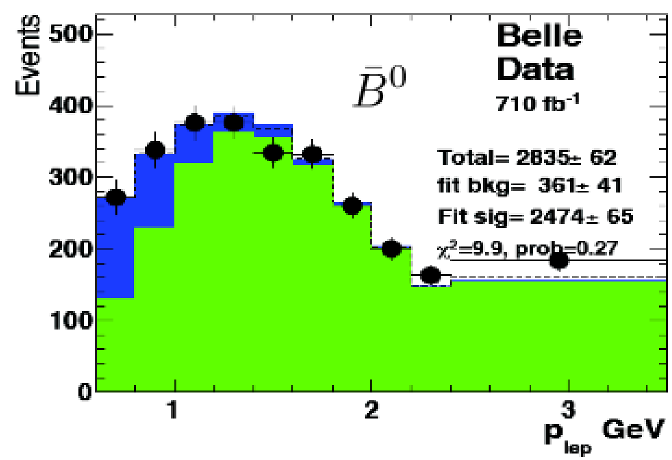
$B \to D^{(*)} X l \nu$ with hadronic tag

Shown at ICHEP 2012

- 703/fb Belle Υ(4S) data
- Second B meson fully reconstructed (hadronic tag)
- Charmed meson reconstructed
- Secondary and fake lepton bkg. subtracted from a fit to lepton momentum
- Signals extracted from a 2d fit to M_{bc} and M_D (D modes) and M_{bc} and Δm (D* modes)

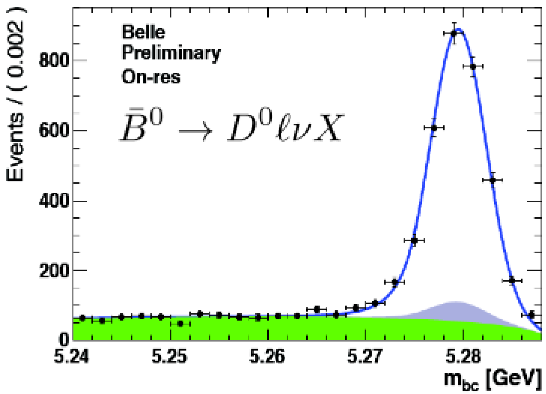
$$\left.\begin{array}{l} D^0 \to K^-\pi^+(\pi^+\pi^-) \\ D^- \to K^-\pi^-\pi^+ \\ D^{*0} \to D^0\pi^0_{\rm slow} \\ D^{*+} \to D^0\pi^+_{\rm slow} \end{array}\right\}$$

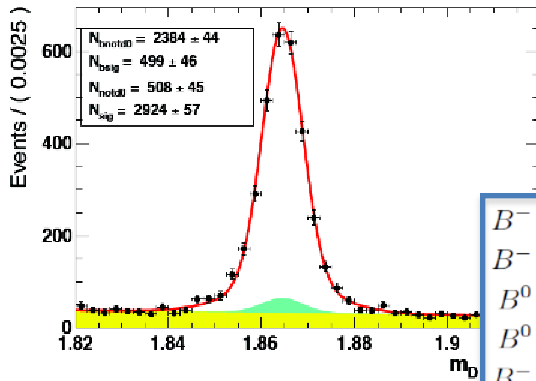
x 2 B flavours
= 8 different modes



$B \to D^{(*)}Xl\nu$ with hadronic tag

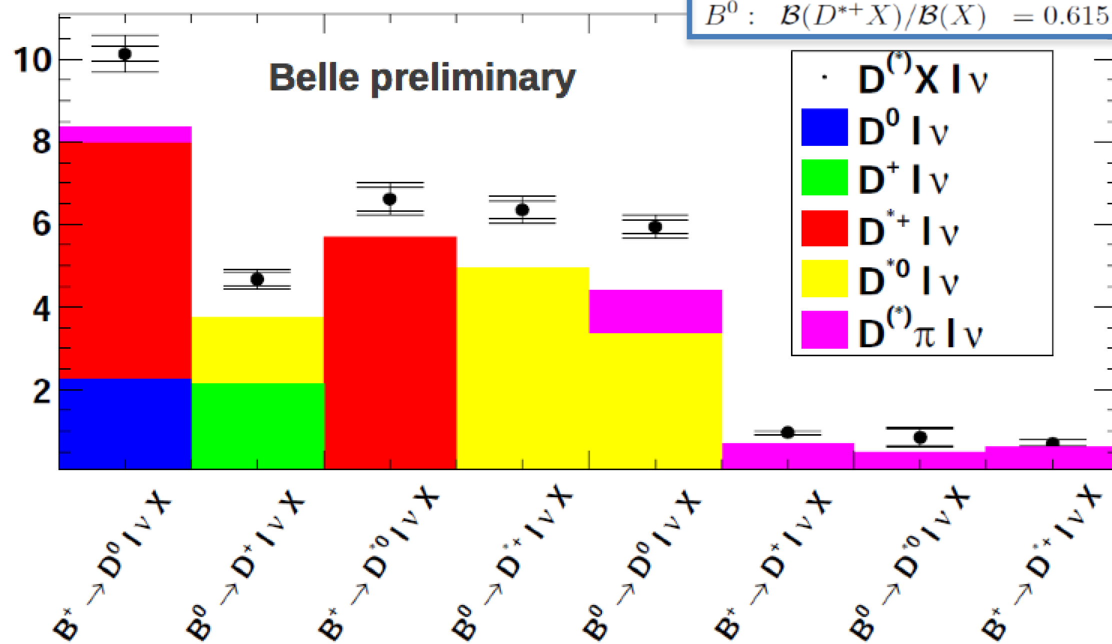
Shown at ICHEP 2012





$B^0 \to D^0 l\nu X$

B^- :	$\mathcal{B}(D^0X)/\mathcal{B}(X)$	$= 0.922 \pm 0.016_{\text{stat.}} \pm 0.011_{\mathcal{B}(D)} \pm 0.036_{\text{sys}}$
B^- :	$\mathcal{B}(D^+X)/\mathcal{B}(X)$	$= 0.088 \pm 0.004_{\text{stat.}} \pm 0.002_{\mathcal{B}(D)} \pm 0.005_{\text{sys}}$
B^0 :	$\mathcal{B}(D^0X)/\mathcal{B}(X)$	$= 0.575 \pm 0.016_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.022_{\text{sys}}$
B^0 :	$\mathcal{B}(D^+X)/\mathcal{B}(X)$	$= 0.452 \pm 0.007_{\text{stat.}} \pm 0.010_{\mathcal{B}(D)} \pm 0.021_{\text{sys}}$
B^- :	$\mathcal{B}(D^{*0}X)/\mathcal{B}(X)$	$= 0.597 \pm 0.026_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.024_{\text{sys}}$
B^- :	$\mathcal{B}(D^{*+}X)/\mathcal{B}(X)$	$= 0.064 \pm 0.007_{\text{stat.}} \pm 0.008_{\mathcal{B}(D)} \pm 0.004_{\text{sys}}$
B^0 :	$\mathcal{B}(D^{*0}X)/\mathcal{B}(X)$	$= 0.081 \pm 0.020_{\text{stat.}} \pm 0.009_{\mathcal{B}(D)} \pm 0.006_{\text{sys}}$
B^0 :	$\mathcal{B}(D^{*+}X)/\mathcal{B}(X)$	$= 0.615 \pm 0.021_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.024_{\text{sys}}$



- Results compared to current HFAG/PDG expectation

$B \rightarrow D^{**} l\nu$ mystery

Charm state X_c	$\mathcal{B}(B^+ \rightarrow X_c\, \ell^+\, \nu)$
D	(2.31 ± 0.09) %
D^*	(5.63 ± 0.18) %
$\sum D^{(*)}$	**(7.94 ± 0.20) %**
$D_0^* \rightarrow D\,\pi$	(0.41 ± 0.08) %
$D_1^* \rightarrow D^*\,\pi$	(0.45 ± 0.09) %
$D_1 \rightarrow D^*\,\pi$	(0.43 ± 0.03) %
$D_2^* \rightarrow D^{(*)}\,\pi$	(0.41 ± 0.03) %
$\sum D^{**} \rightarrow D^*\pi$	**(1.70 ± 0.12) %**
$D\,\pi$	(0.66 ± 0.08) %
$D^*\,\pi$	(0.87 ± 0.10) %
$\sum D^*\pi$	**(1.53 ± 0.13) %**
$\sum D^{(*)} + \sum D^*\pi$	**(9.47 ± 0.24) %**
$\sum D^{(*)} + \sum D^{**} \rightarrow D^{(*)}\pi$	**(9.64 ± 0.23) %**
Inclusive X_c	**(10.92 ± 0.16) %**

broad states $(0.86 \pm 0.12)\%$

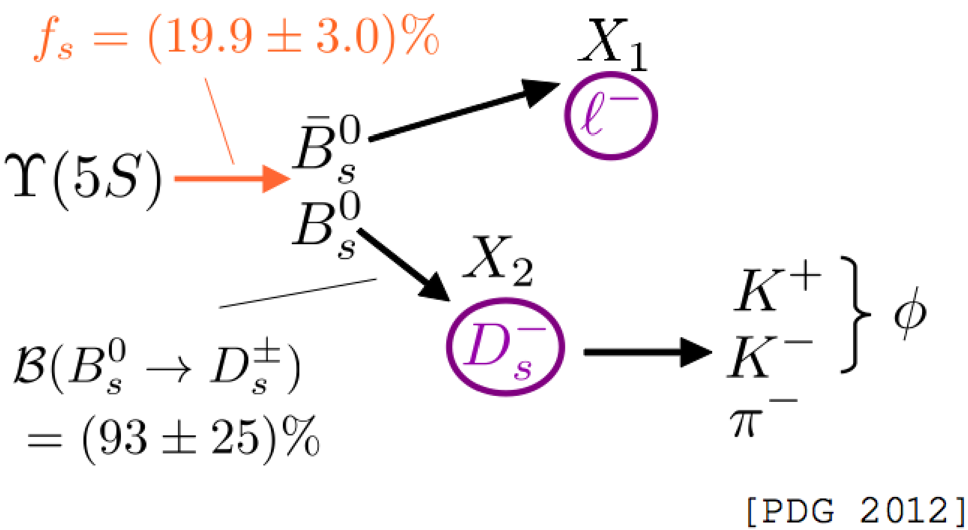
narrow states $(0.84 \pm 0.04)\%$

- Inclusive-exclusive gap of (1.45 +/- 0.29)%
- 1/2 vs. 3/2 puzzle
- Belle II might clarify the situation by measuring $B \rightarrow D^{(*)} n\pi l\nu$

Sascha Turczyk
CKM 2012 workshop

$B_s \to Xl\nu$ inclusive semileptonic

To appear in PRD



our measurement — external parameters

$$\frac{N(D_s^- \ell^-)}{N(D_s^-)} = \frac{N_s(D_s^- \ell^-) + N_{u,d}(D_s^- \ell^-)}{N_s(D_s^-) + N_{u,d}(D_s^-)}$$

$$N(D_s^- \ell^-) \propto f_s \cdot \mathcal{B}(B_s^0 \to X \ell^+ \nu_\ell)$$

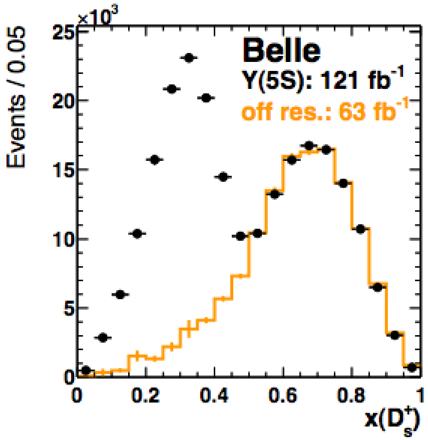
Background from $B_{u,d}$ decays

- 121/fb Belle Y(5S) data
- Tag B_s decays with a fully reconstructed D_s
- Measure same sign $D_s^- l^-$ relative to the number of D_s
- $B_{u,d}$ contamination estimated using PDG parameters

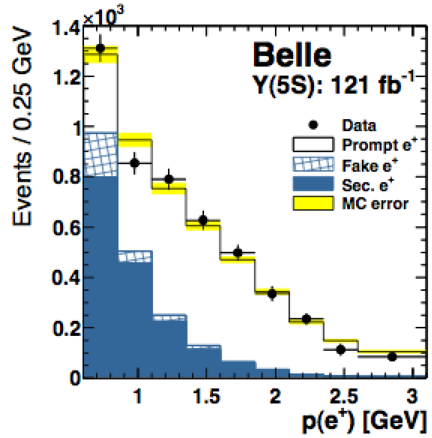
$B_s \to X l \nu$ inclusive semileptonic

To appear in PRD

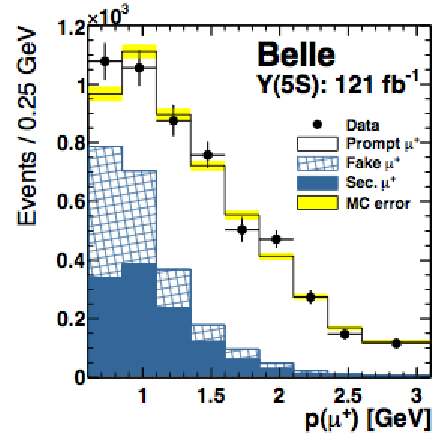
D_s^- sample



$D_s^- e^-$ sample



$D_s^- \mu^-$ sample



$R = N(D_s^- l^-)/N(D_s^-)$

Mode	Ratio $\mathcal{R} \times 10^{-4}$	χ^2/ndf
e	$428 \pm 20 \pm 13$	6.4 / 7
μ	$470 \pm 23 \pm 16$	6.7 / 7
e, μ	$444 \pm 16 \pm 13$	—

$Br(B_s \to X l \nu)$

$$\ell = e \quad [10.1 \pm 0.6(\text{stat}) \pm 0.4(\text{syst}) \pm 0.6(\text{ext})]\%$$
$$\ell = \mu \quad [11.3 \pm 0.7(\text{stat}) \pm 0.5(\text{syst}) \pm 0.7(\text{ext})]\%$$
$$\ell = e, \mu \quad [10.6 \pm 0.5(\text{stat}) \pm 0.4(\text{syst}) \pm 0.6(\text{ext})]\%$$

Determination of $|V_{ub}|$

Exclusive

$B \to \pi l \nu$

$$\frac{d\Gamma(B^0 \to \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

- Form factor f_+ from lattice QCD [PRD73, 074502; PRD79, 054507] or from QCD sum rules [PRD83, 094031; PRD 71, 014015]

Inclusive

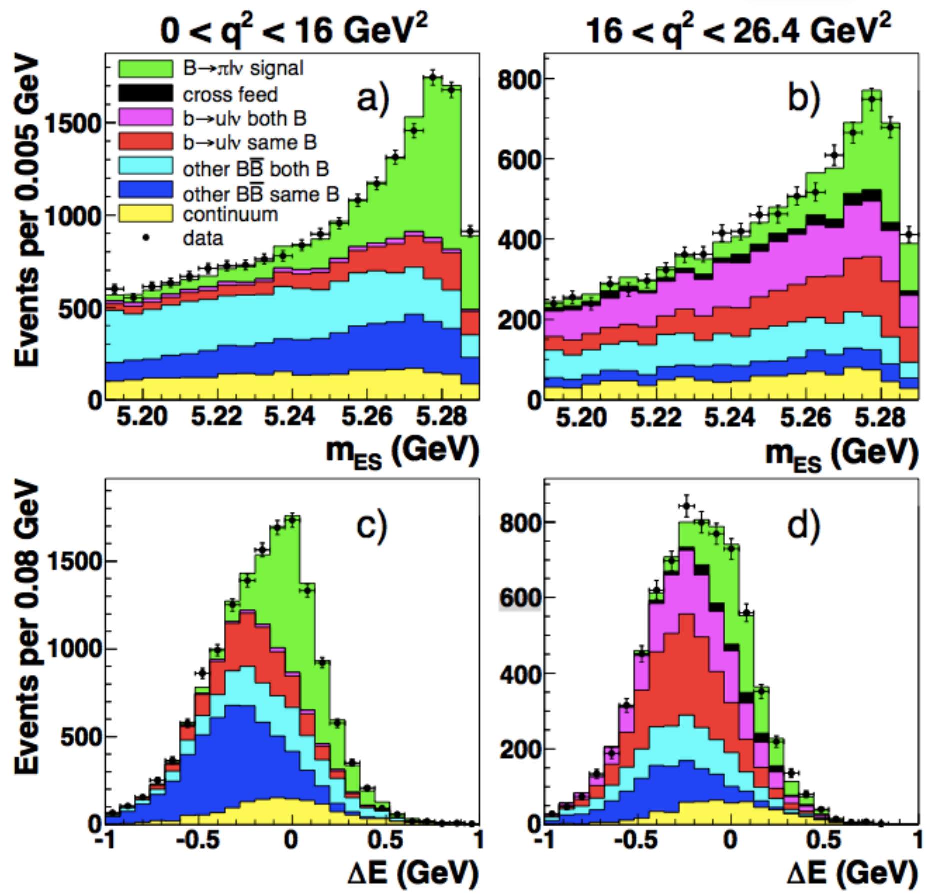
$B \to X_u l \nu$

- Also based on the OPE [NPB699, 335; JHEP01, 097; JHEP10, 058]
- Experimental selections can comprise the convergence of the OPE $\to$ shape function

$B \to \pi l \nu$ untagged

PRD 86, 092004 (2012)

- 416/fb of BaBar Y(4S) data
- Reconstruct only $\pi e/\pi\mu$, infer neutrino momentum from p_{miss} (loose neutrino reconstruction technique)
- About 12,000 signal events, S/N ~0.1
- Partial branching fractions obtained in 12 q^2 bins
- This analysis also includes a study of $B \to \omega/\eta/\eta' l \nu$ (BF and FF shape) with the same technique



$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$
$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$

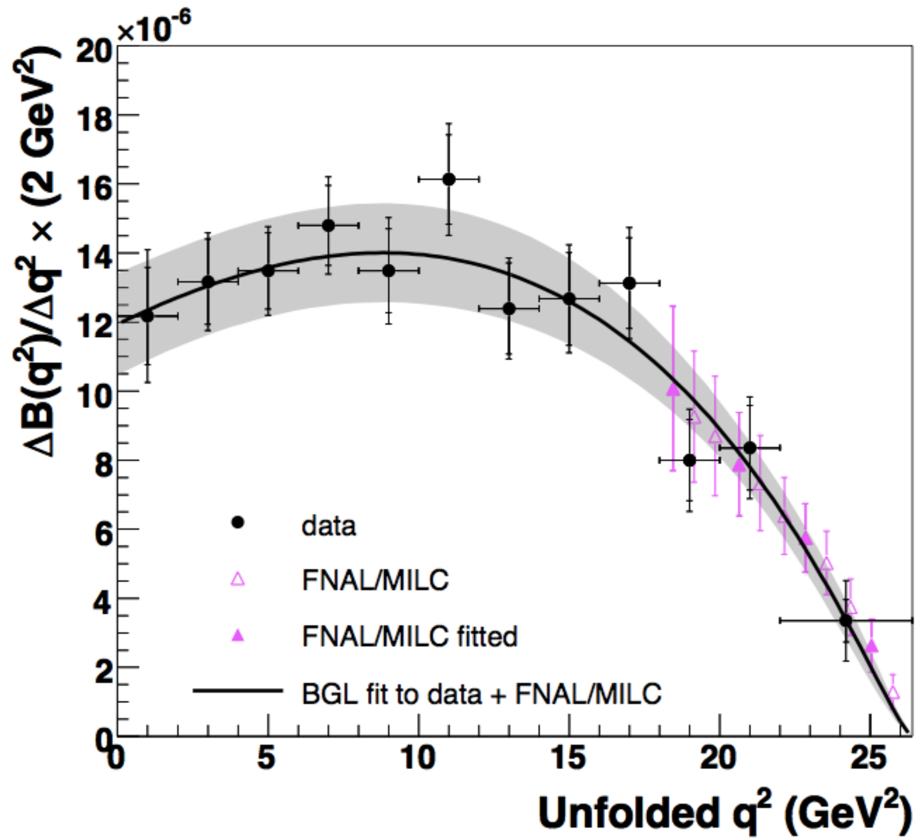
$B \to \pi l \nu$ untagged

PRD 86, 092004 (2012)

- FF parameterization: Boyd-Grinstein-Lebed

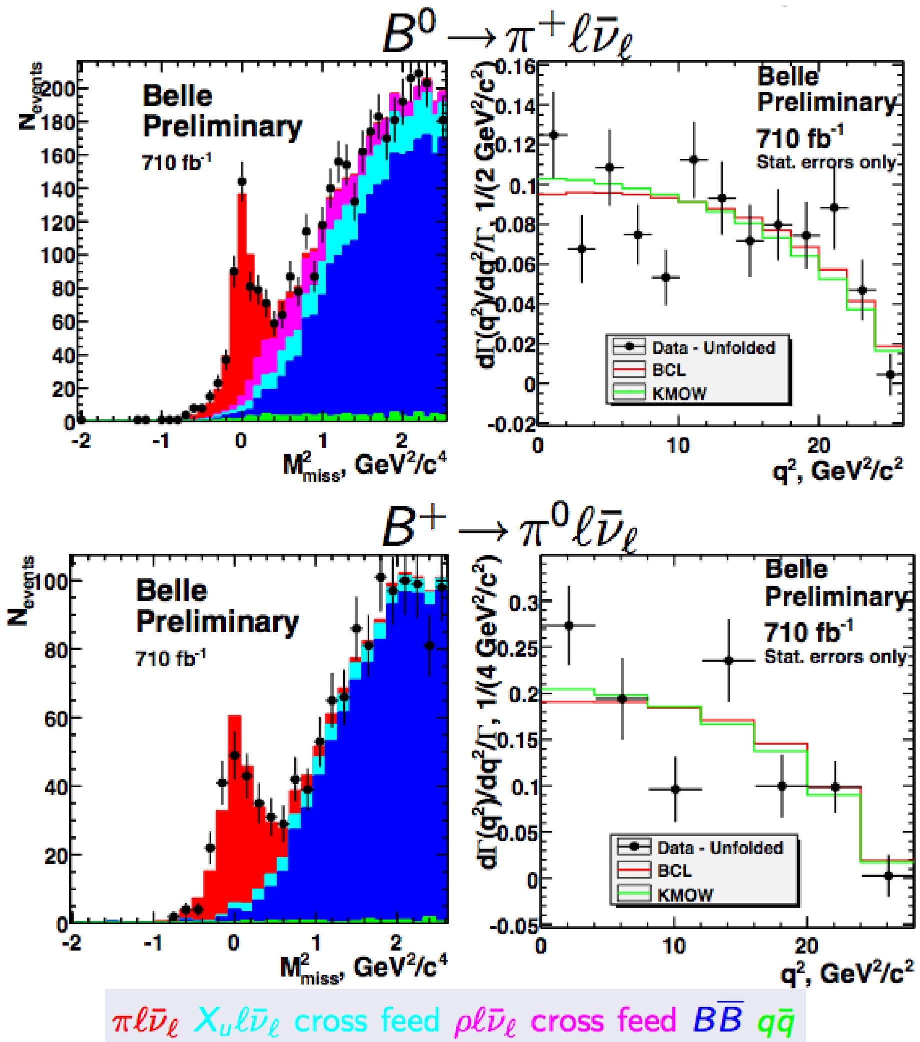
$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\phi(q^2, q_0^2)} \sum_{k=0}^{k_{max}} a_k(q_0^2)[z(q^2, q_0^2)]^k \qquad z(q^2, q_0^2) = \frac{\sqrt{m_+^2 - q^2} - \sqrt{m_+^2 - q_0^2}}{\sqrt{m_+^2 - q^2} + \sqrt{m_+^2 - q_0^2}}$$

- Combined fit with FNAL/MILC lattice data yields $|V_{ub}|$ = $(3.25 +/- 0.31) \times 10^{-3}$
- Alternative extractions of $|V_{ub}|$ (using LCSR/LQCD in regions of q^2) consistent with the combined fit



$B \to \pi l \nu$ with hadronic tag

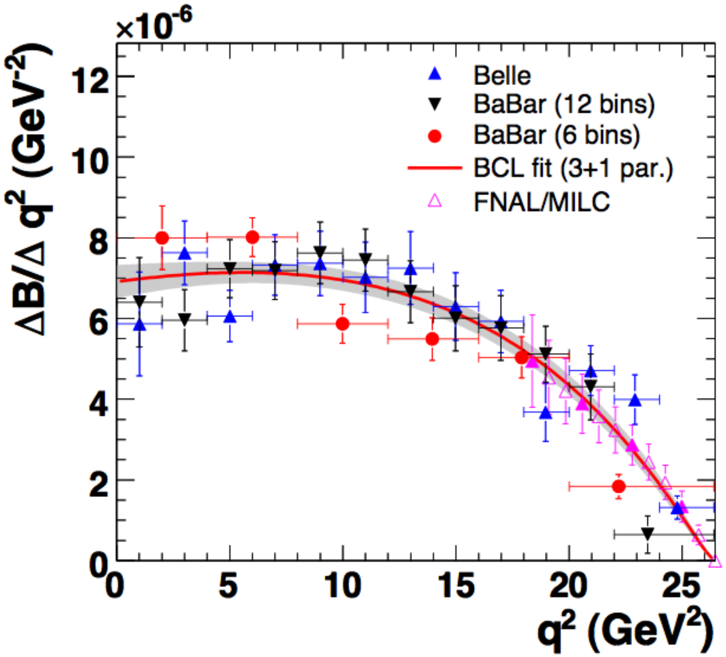
Shown at Lake Louise 2012

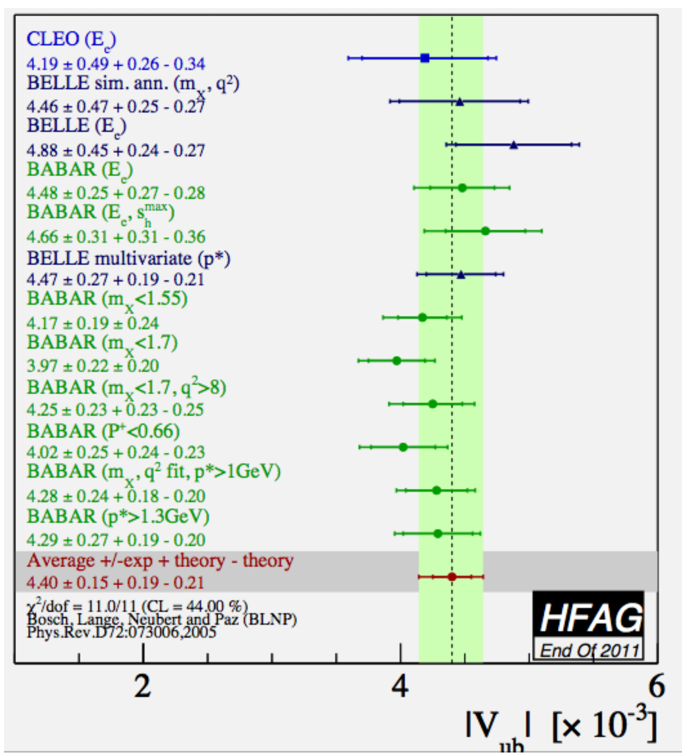


- 703/fb of Belle Y(4S) data
- Hadronic tag
- Yield extracted from M^2_{miss} in 13 (7) bins of q^2 for $B^0 \to \pi^+ l \nu$ ($B^+ \to \pi^0 l \nu$)
- Also $B \to \rho/\rho^0/\omega/\eta(')l\nu$ measured

X_u	Yield	$\mathcal{B} \times 10^4$
π^+	461 ± 28	$1.49 \pm 0.09 \pm 0.07$
π^0	230 ± 22	$0.80 \pm 0.08 \pm 0.04$

X_u	Theory	q^2, GeV/c^2	$\lvert V_{ub}\rvert \times 10^3$
π^0	LCSR1	< 12	$3.30 \pm 0.22 \pm 0.09^{+0.35}_{-0.30}$
	LCSR2	< 16	$3.62 \pm 0.20 \pm 0.10^{+0.60}_{-0.40}$
	HPQCD	> 16	$3.45 \pm 0.31 \pm 0.09^{+0.58}_{-0.38}$
	FNAL/MILC	> 16	$3.30 \pm 0.30 \pm 0.09^{+0.36}_{-0.30}$
π^+	LCSR1	< 12	$3.38 \pm 0.14 \pm 0.09^{+0.36}_{-0.32}$
	LCSR2	< 16	$3.57 \pm 0.13 \pm 0.09^{+0.59}_{-0.39}$
	HPQCD	> 16	$3.86 \pm 0.23 \pm 0.10^{+0.66}_{-0.44}$
	FNAL/MILC	> 16	$3.69 \pm 0.22 \pm 0.09^{+0.41}_{-0.34}$





$|V_{ub}|$

Exclusive (BCL fit)

$|V_{cb}| = (3.23 +/- 0.30) \times 10^{-3}$

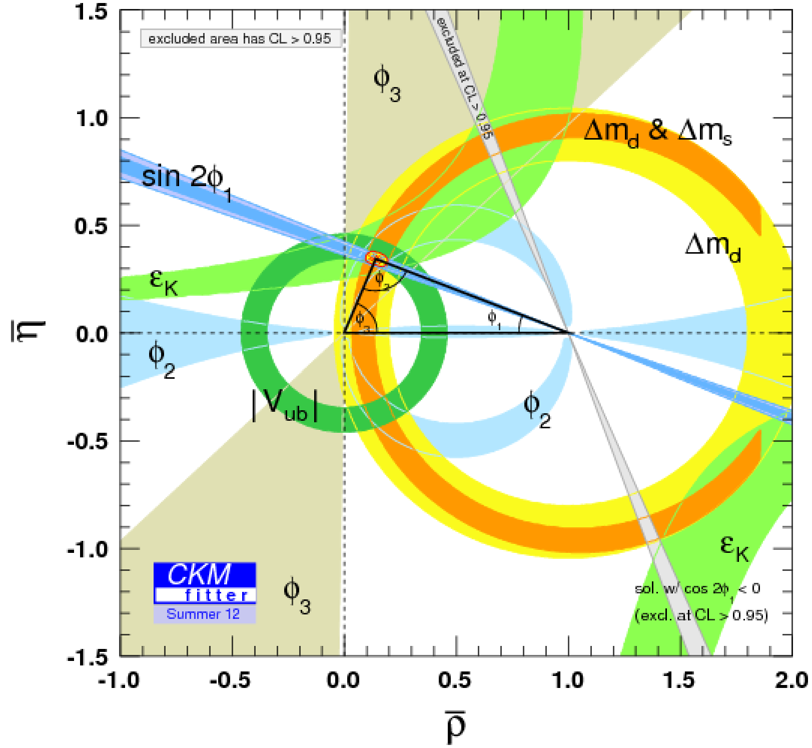
Inclusive (BLNP)

$|V_{cb}| = (4.40 +/- 0.15_{exp} +/- 0.20_{th}) \times 10^{-3}$

HFAG preprint [arXiv:1207.1158]

- Exclusive and inclusive agree at the level of ~3 sigma

Unitarity triangle



Average $|V_{ub}|$ used by CKM fitter (ICHEP 2012)

$|V_{ub}| = (3.75 +/- 0.29) \times 10^{-3}$

UT fit result

$|V_{ub}| = (3.49 +0.21/-0.09) \times 10^{-3}$

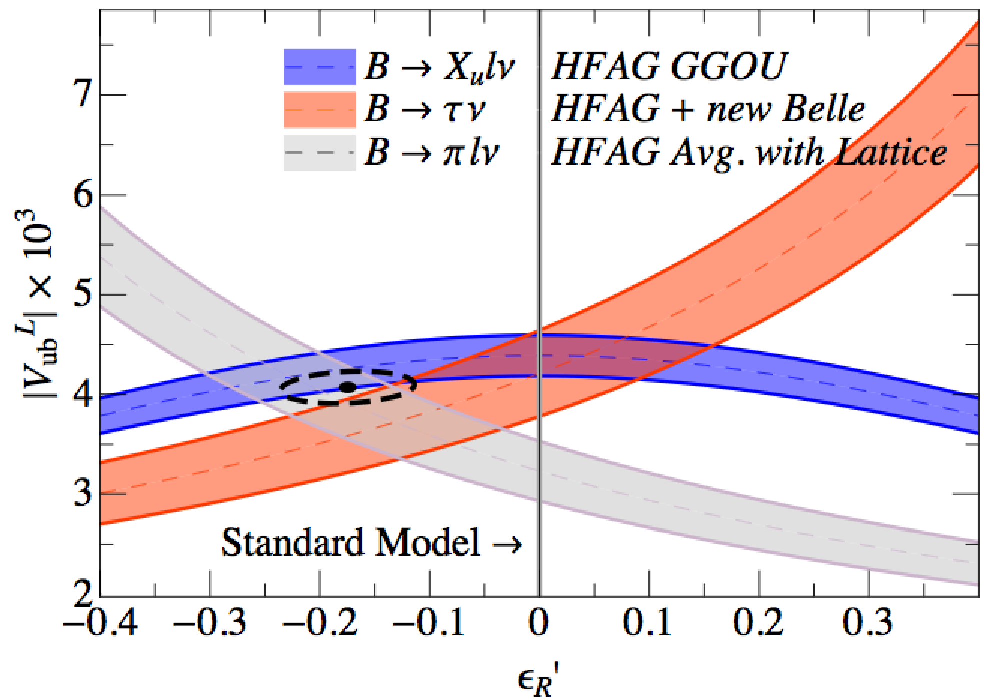
- Exclusive/inclusive average nicely fits SM
- However, given the exclusive/inclusive discrepancy, there is clearly room for NP in the UT

Right-handed currents

- Add right-handed currents ($|V_{ub}|=|V_{ub}^L|$)
  - $B \to \pi l\nu$ goes as $|V_{ub}^L+V_{ub}^R|^2$
  - $B \to \tau\nu$ goes as $|V_{ub}^L-V_{ub}^R|^2$
  - $B \to X_u l\nu$ goes as $|V_{ub}^L|^2+|V_{ub}^R|^2$
- Can fit the data with ~17% RHC contribution

Florian Bernlochner
CKM 2012 workshop

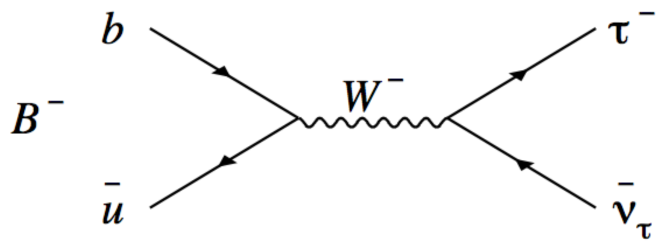
Proposed by
[hep-ph/0505166]
[arXiv:0907.2461]
[arXiv:1007.1993]

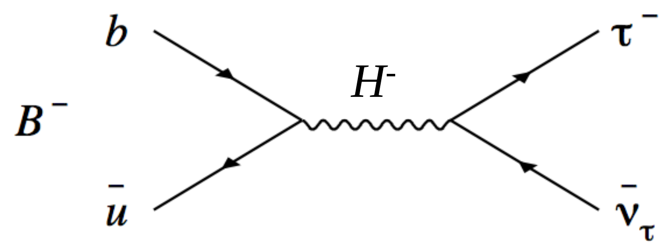


(Semi)leptonic B decays with τ

Search for the charged Higgs in $B \to \tau\nu$

SM



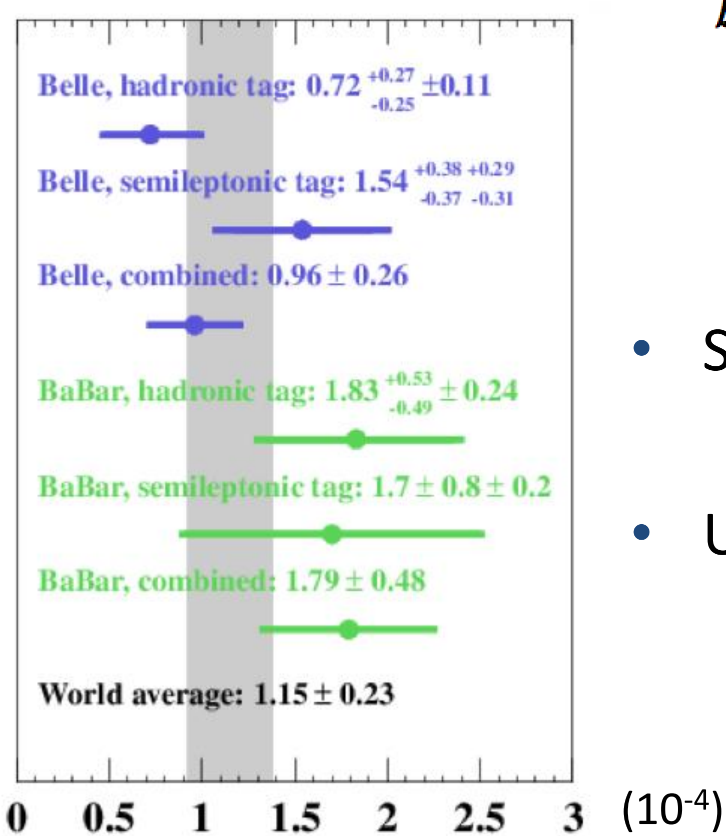


2HDM
Type II

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}) = \mathcal{B}_{\rm SM} \times r_H$$

$$r_H = \left(1 - \tan^2\beta \frac{m_{B^-}^2}{m_{H^-}^2}\right)^2$$

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



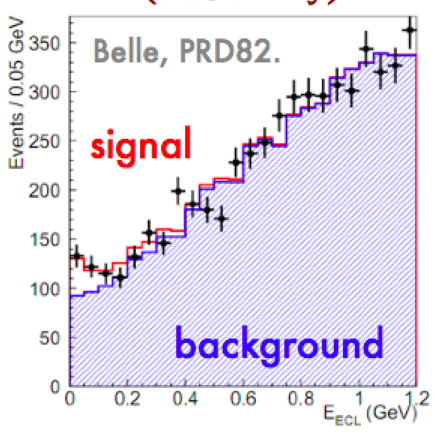
- SM expectation
  - $Br(B \to \tau\nu) = (1.20 +/- 0.25) \times 10^{-4}$
- UT fit result
  - $Br(B \to \tau\nu) = (0.72 +0.12/-0.08) \times 10^{-4}$

Measurement of $B \to \tau\nu$

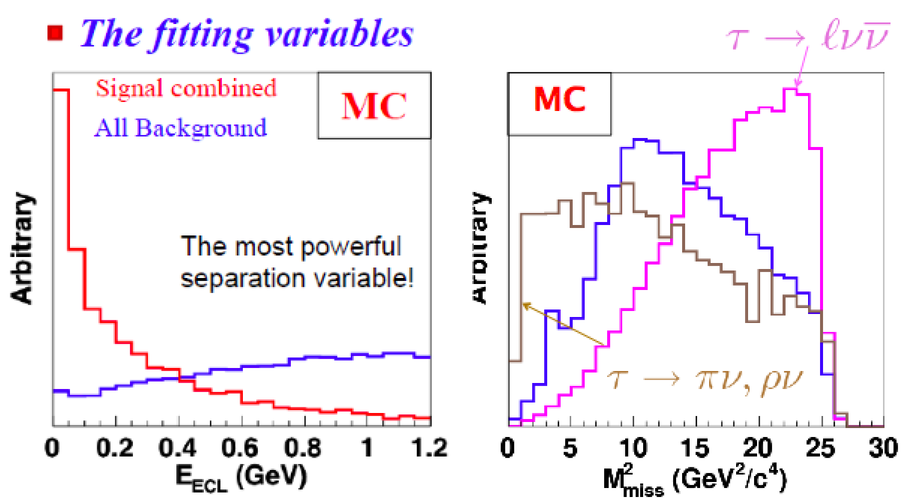
PRL 110, 131801 (2013)

- 703/fb of Υ(4S) data
- 4 signal tau modes: $\tau \to e\nu\nu, \mu\nu\nu, \pi\nu, \rho\nu$
- New hadronic tag (sample x3 compared to 2006 analysis)
- 2d fit to E_{ECL} and M^2_{miss} (2006: E_{ECL} only)
  - Improve sensitivity by 20%
  - More robust against peaking backgrounds

previous analyses
(E_{ECL} only)



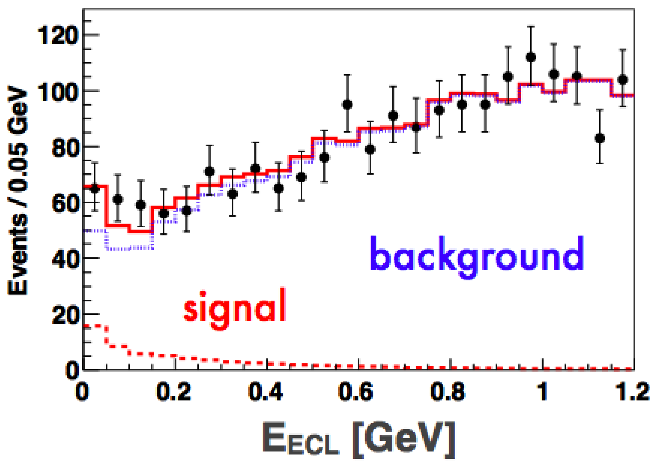
■ *The fitting variables*



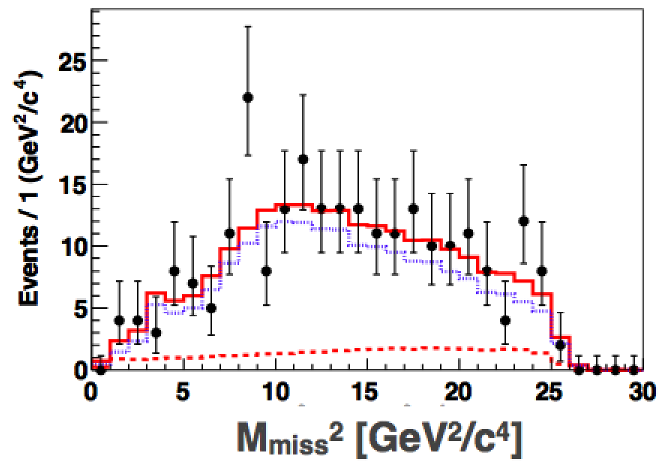
Measurement of B $\rightarrow \tau\nu$

PRL 110, 131801 (2013)

- Simultaneous fit to all four tau modes



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



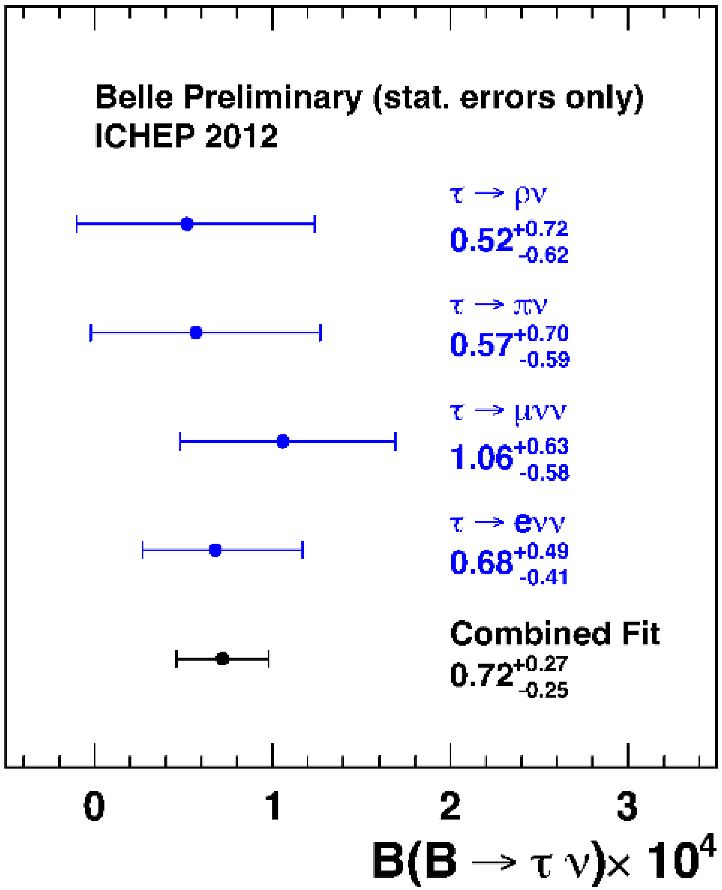
(Projection for E_{ECL} < 0.2 GeV)

- Signal yield: 62 +23/-22 +/- 6 (3σ including systematics)
- Br(B $\rightarrow \tau\nu$) = (0.72 +0.27/-0.25 +/- 0.11) x 10^{-4}

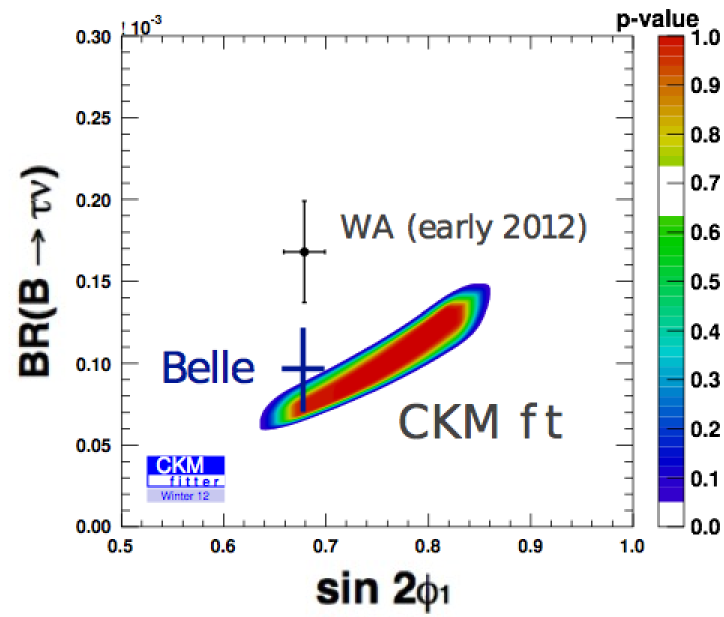
Measurement of $B \to \tau\nu$

PRL 110, 131801 (2013)

- Consistency between tau 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	$0.72^{+0.27}_{-0.25}$



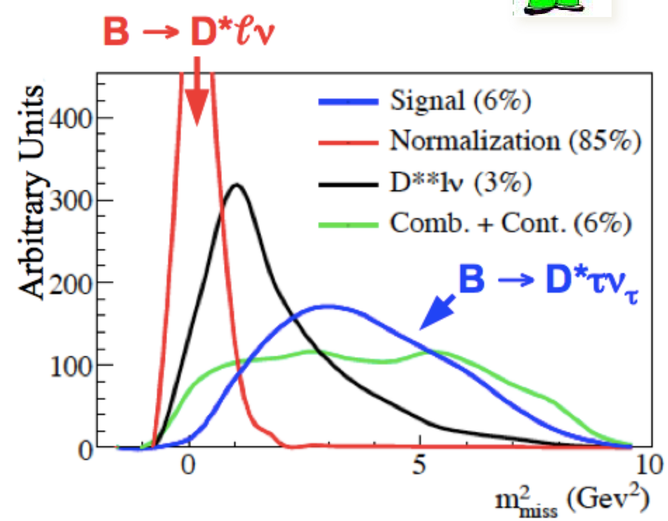
$B \to D^{(*)}\tau\nu$

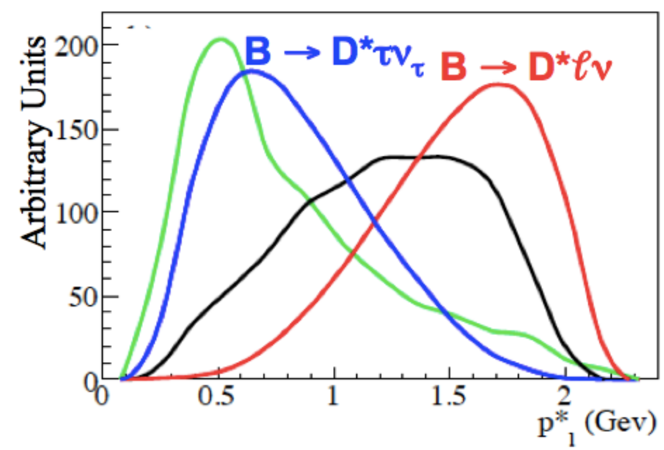
PRL 109, 101802 (2012)
arXiv:1303.0571 [hep-ex], submitted to PRD

- 426/fb of BaBar Υ(4S) data
- Hadronically tagged events
- Simultaneous unbinned ML fit
  - 4 signal samples: D^0l, $D^{*0}l$, D^+l, $D^{*+}l$
  - 2 observables:

$m_{miss}^2 = (p_{e+e-} - p_{tag} - p_{D(*)} - p_{\ell})^2$

p^*_{ℓ} in the B_{sig} rest-frame

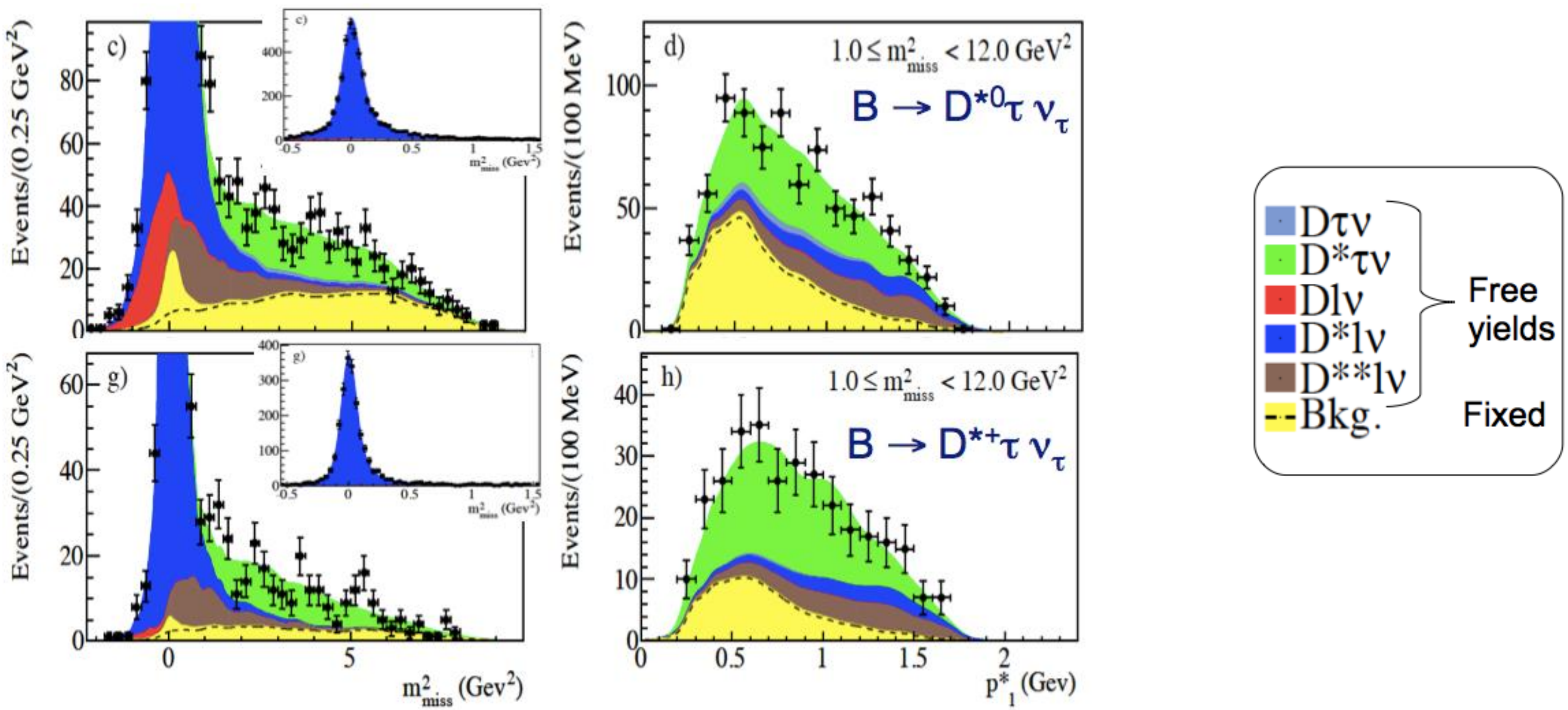




Fit results $B \to D^{*}\tau\nu$

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^{*}\tau\nu$
N_{sig}	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^{*})$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

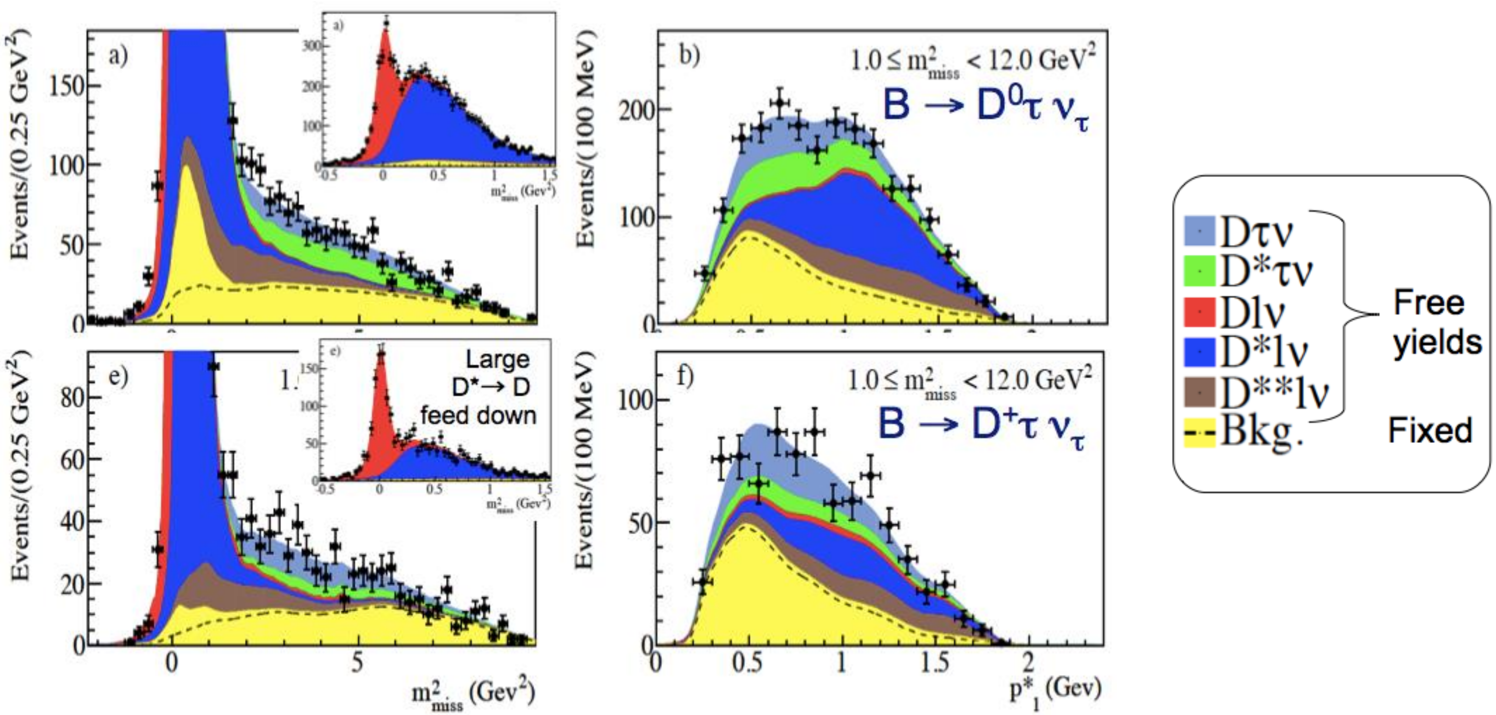
Statistical errors only



Fit results $B \to D\tau\nu$

	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Statistical errors only



Results and systematic uncertainties

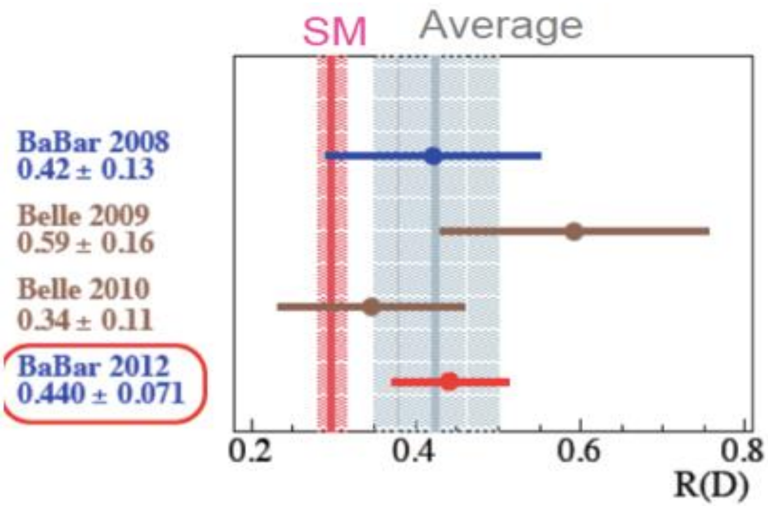
Decay	$N_{\rm sig}$	$N_{\rm norm}$	$R(D^{(*)})$	$\mathcal{B}(B\to D^{(*)}\tau\nu)$ (%)	$\Sigma_{\rm tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440\pm0.058\pm0.042$	$1.02\pm0.13\pm0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332\pm0.024\pm0.018$	$1.76\pm0.13\pm0.12$	13.2

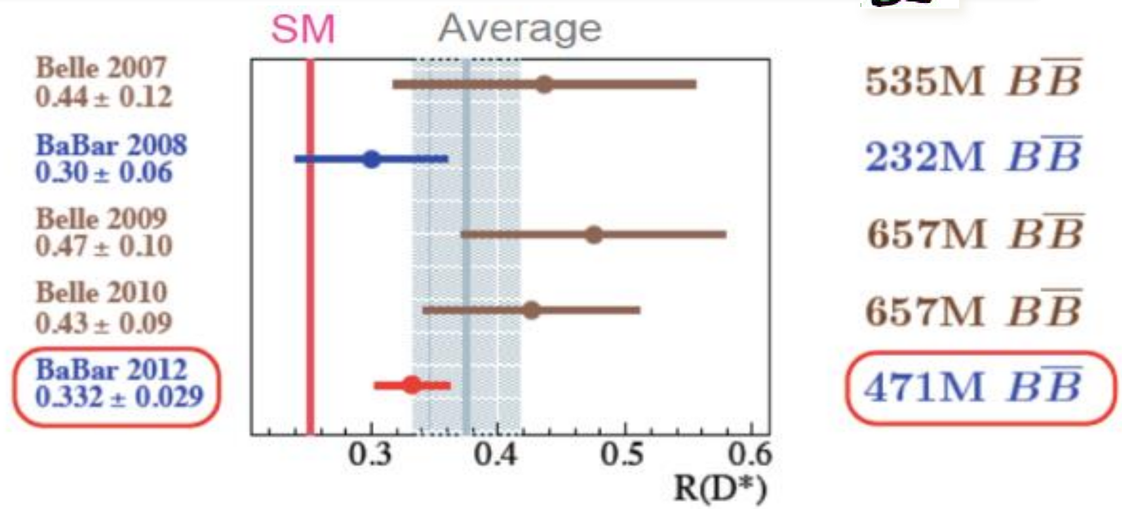
$$\mathcal{R}(D)=\frac{\mathcal{B}(\overline{B}\to D\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B}\to D\ell^-\overline{\nu}_\ell)},$$

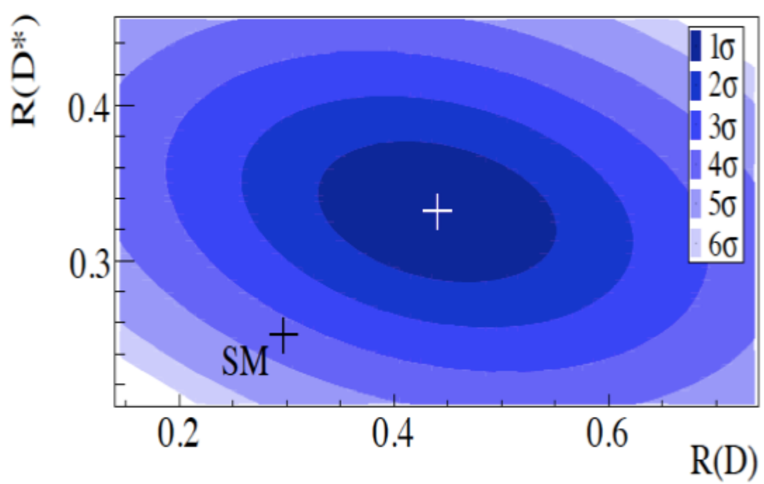
$$\mathcal{R}(D^*)=\frac{\mathcal{B}(\overline{B}\to D^*\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B}\to D^*\ell^-\overline{\nu}_\ell)}.$$

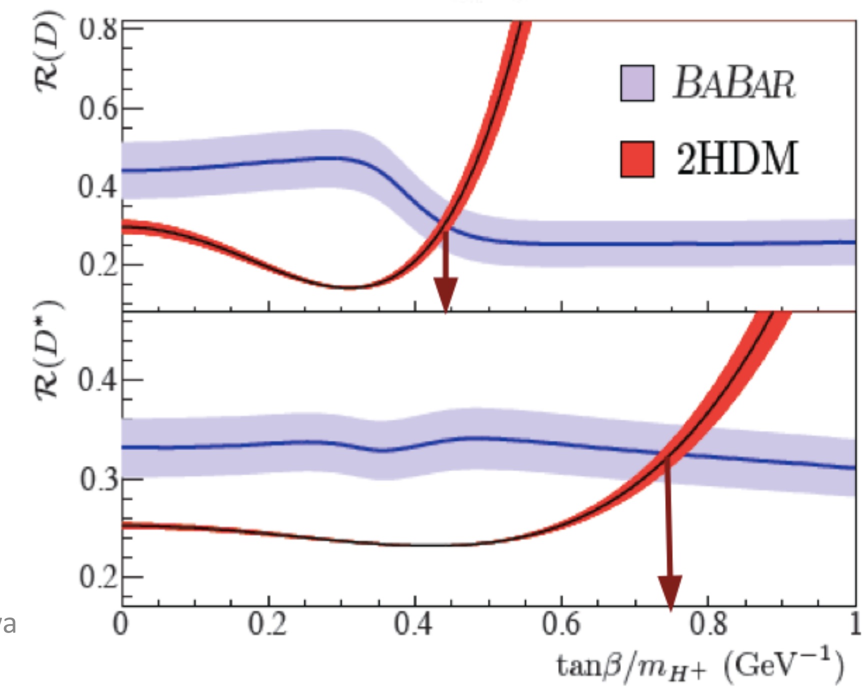
	R(D)	R(D*)	$\rho_{\rm corr}$
D** τ/l ν	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Continuum and BB bkg	4.9	2.7	-0.30
$\varepsilon_{\rm sig}/\varepsilon_{\rm norm}$	2.6	1.6	0.22
Syst. Uncertainty	9.5	5.3	0.05
Stat. Uncertainty	13.1	7.1	-0.45
Total Uncertainty	16.2	9.0	-0.27

SM and 2HDM predictions of $R(D^{(*)})$









SM prediction is excluded at 3.4σ

Christoph Schwa

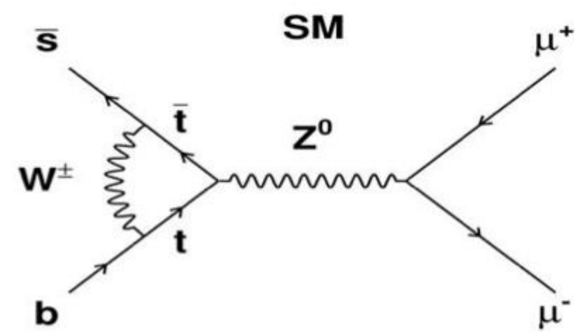
$B_{(s)} \to l^+l^-$

$B_{s,d} \to \mu^+\mu^-$

- Double suppression: FCNC process and helicity suppression
- Sensitive to contributions in the scalar/pseudo-scalar sector, extended Higgs models

Mode	SM
$B_s \to \mu^+\mu^-$, time averaged	$(3.54 \pm 0.30) \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$(0.107 \pm 0.01) \times 10^{-9}$

Buras, Isidori: arXiv:1208.0934
De Bruyn, et al [1204.1737] uses LHCb-CONF-2012-002



BR expressed in Wilson coefficients:

$$BR(B_s \to \mu^+\mu^-) \propto \left|C_S - C'_S\right|^2 \left(1 - \frac{4m_\mu^2}{m_{Bs}^2}\right) + \left|(C_P - C'_P) + \frac{2m_\mu}{m_{Bs}}(C_{10} - C'_{10})\right|^2$$

$B_{s,d} \rightarrow \mu^+\mu^-$

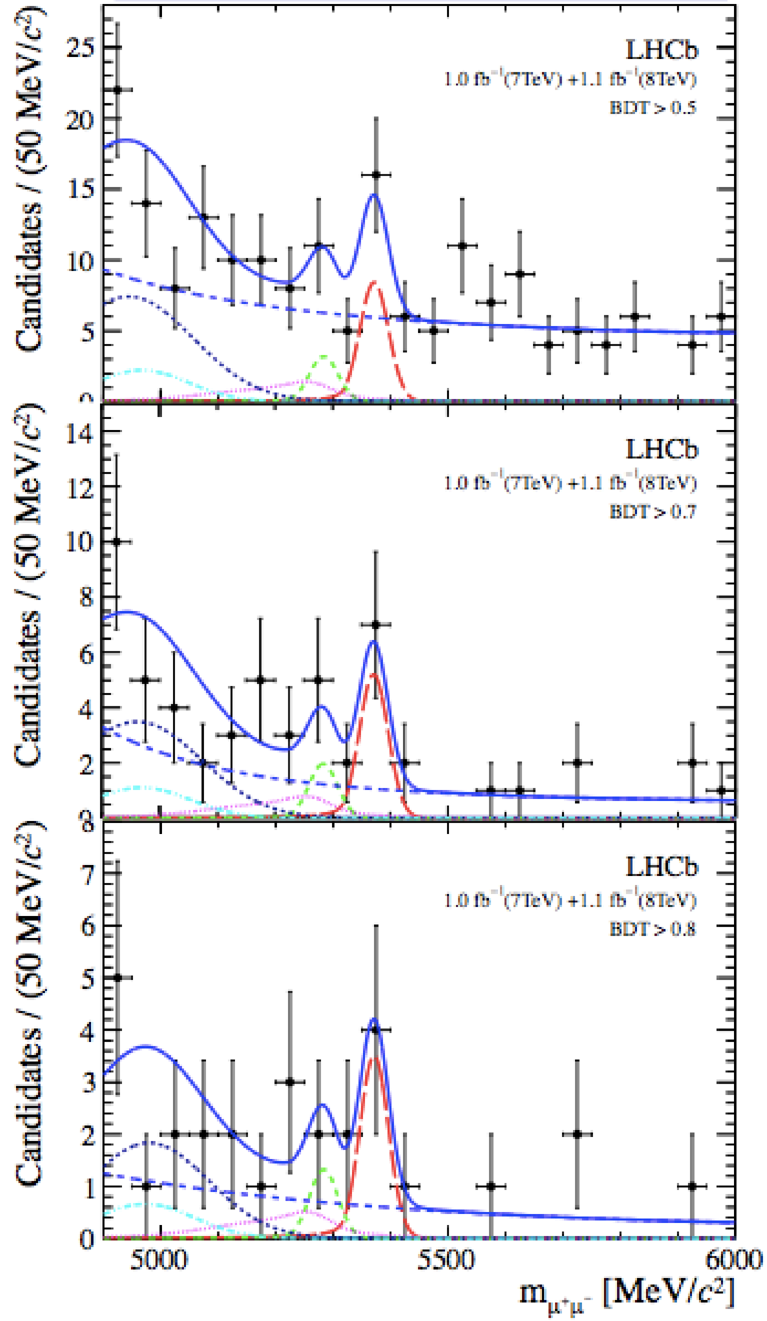
PRL 110, 021801 (2013)

- Combined analysis of 2011 and 2012 data
- BDT for signal classification
  - Peaking backgrounds from $B_{(S)} \rightarrow hh$, $\pi\mu\nu$, $\pi\mu\mu$
- 3.5σ evidence of $B_s \rightarrow \mu^+\mu^-$

$$BR(B_s \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

- $BR(B \rightarrow \mu^+\mu^-) < 9.4 \times 10^{-10}$ at 95% C.L.

$B_s \rightarrow \mu^+\mu^-$ emerging



SUMMARY

Summary

- I have reviewed results on semileptonic and leptonic B decays which are sensitive to a range of extensions to the SM
- The Belle II leptonic super flavor factory will allow to improve these results and to access new modes, e.g., $B_s \rightarrow \tau^+\tau^-$

From the 2013 briefing book of the European Strategy Group:

Table 3.2: List of key flavour-changing processes in the quark sector.

Observables	Comments	Physics issues
CKM angle γ	tree-level	SM input for ΔF=2 tests
→ $\lvert V_{ub}\rvert$	tree-level	SM input for ΔF=2 tests
→ $B_{(s,d)} \rightarrow \ell^+\ell^-$	$\Delta(f_B) < 5$ %	Higgs-mediated FCNC
CPV in B_s	$\sigma \sim 0.01$	new CPV
$B \rightarrow K^{(*)}\ell^+\ell^-, K^{(*)}\nu\nu$	$\sigma \leq 5$ %	non-standard FCNC
→ $B \rightarrow \tau\nu, \mu\nu$	$\Delta(f_B) < 5$ %	scalar charged currents
$K \rightarrow \pi\nu\overline{\nu}$	Δ(BR) < 5 %	non MFV
CPV in charm	uncertainty needs work	new physics up-type quarks

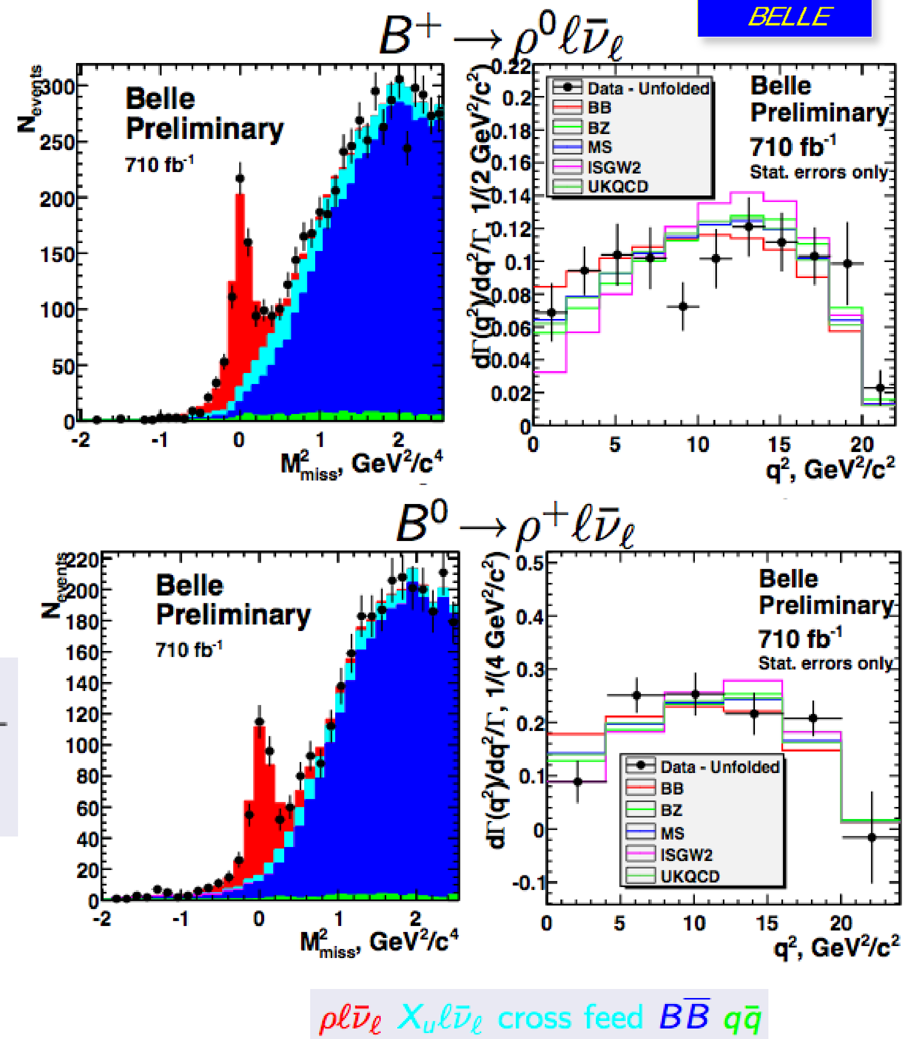
BACKUP

$B \to \rho l \nu$ with hadronic tag

Shown at Lake Louise 2012

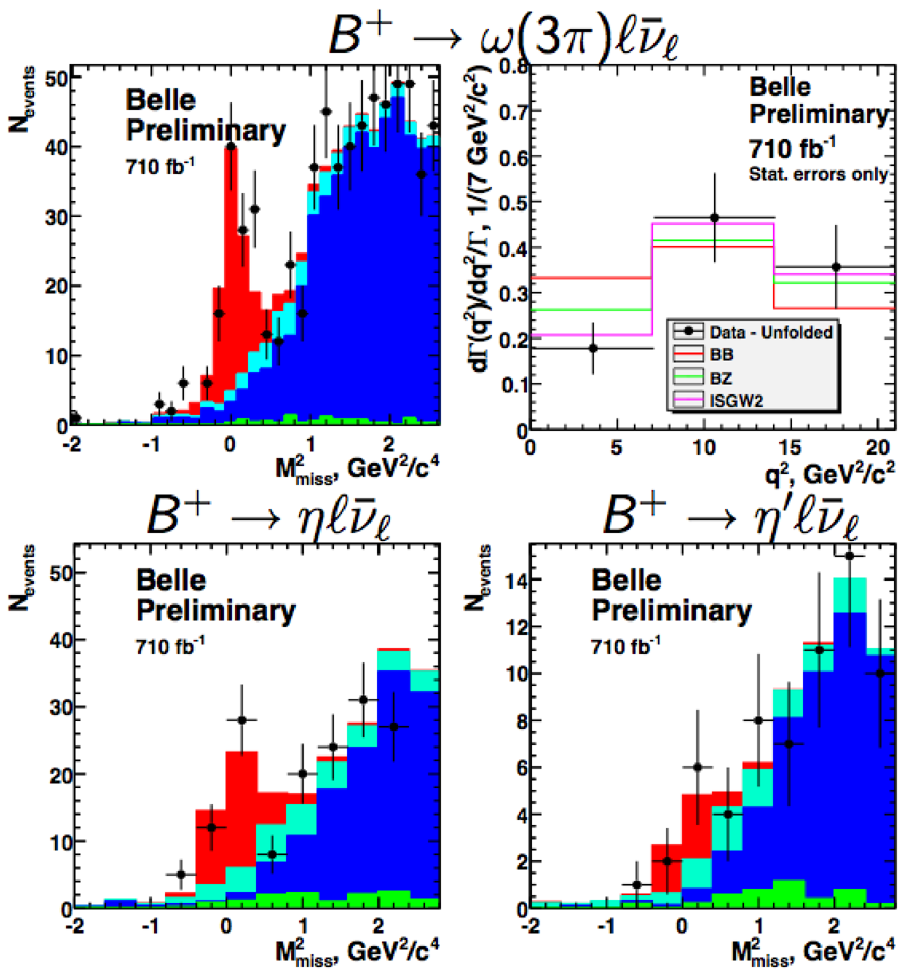
- 703/fb of Belle Y(4S) data
- Hadronic tag
- Yield extracted from M^2_{miss} in 11 (6) bins of q^2 for $B^+ \to \rho^0 l \nu$ ($B^0 \to \rho^+ l \nu$)

X_u	Yield	$\mathcal{B} \times 10^4$
ρ^+	338±28	$3.17 \pm 0.27 \pm 0.18$
ρ^0	632±35	$1.86 \pm 0.10 \pm 0.09$



$B^+ \to \omega l \nu$ and $B^+ \to \eta^{(\prime)} l \nu$

Shown at Lake Louise 2012



Signal $X_u\ell\bar{\nu}_\ell$ cross feed $B\bar{B}$ $q\bar{q}$

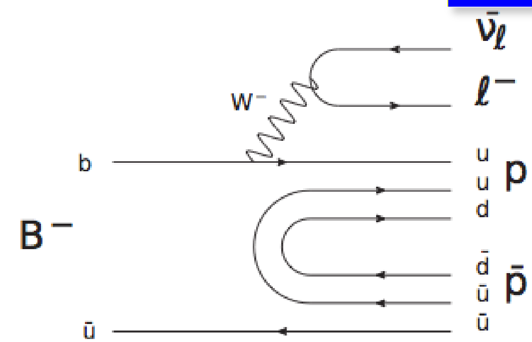
X_u	Yield	$\mathcal{B} \times 10^4$
ω	99 ± 15	$1.09 \pm 0.16 \pm 0.08$
η	39 ± 11	$0.42 \pm 0.12 \pm 0.05$
η'	6.1 ± 4.7	< 0.57 @ 90% CL

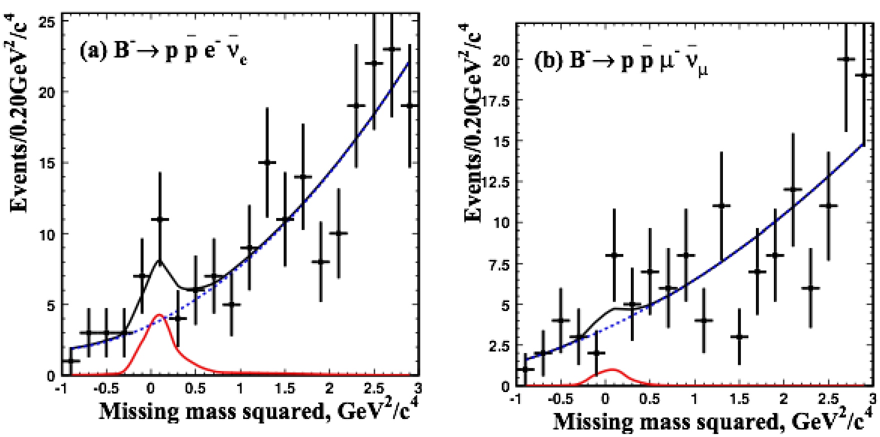
- 703/fb of Belle Y(4S) data
- Soon to be submitted to Phys. Rev. D

Evidence for B → $p\bar{p}l\nu$

Shown at Moriond EW 2013

- 703/fb Υ(4S) data
- Hadronic tag
- Detailed study of proton id
- Signal extracted from M^2_{miss}

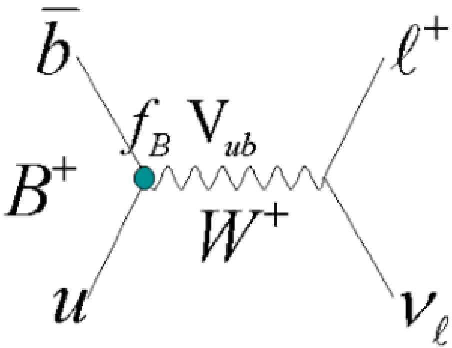




signal significance: 3.19σ

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

Leptonic B decays



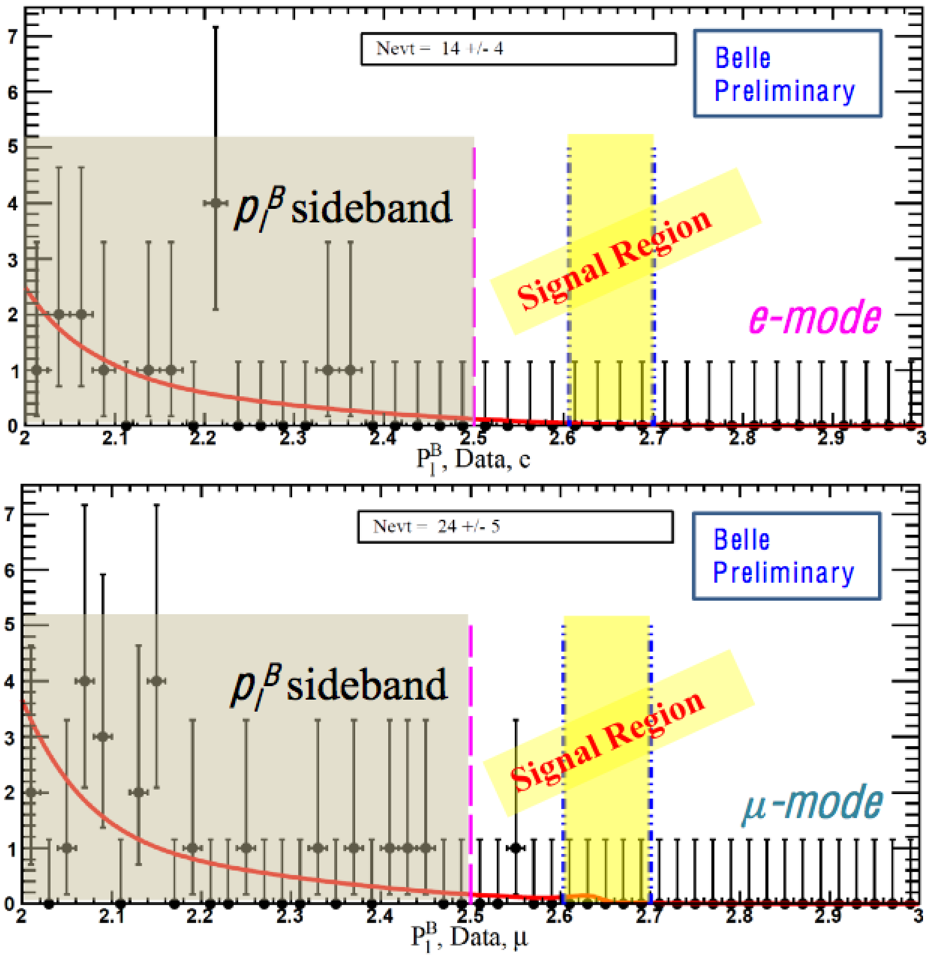
$$\Gamma(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

$$\mathcal{B}(B \to e\nu)_{SM} \sim 10^{-11}$$
$$\mathcal{B}(B \to \mu\nu)_{SM} \sim 3.5 \times 10^{-7}$$
$$\mathcal{B}(B \to \tau\nu)_{SM} \sim 10^{-4}$$

- Helicity suppression $\Gamma(e\nu) << \Gamma(\mu\nu) << \Gamma(\tau\nu)$
- Very clean theoretically,
  might be affected by NP (2HDM, lepto-quark)
- B $\rightarrow$ eν and B $\rightarrow$ $\mu\nu$ are also experimentally clean but beyond the reach of Belle
- B $\rightarrow$ $\tau\nu$ has 2-3 neutrinos in the final state and kinematics cannot be fully reconstructed even with hadronic tagging (high background measurement)

Search for B → lν

Shown at ICHEP 2012



- 703/fb of Y(4S) data
- Hadronic tag
- Limits extracted from lepton momentum distribution

Upper Limit calculated by POLE (Feldman-Cousins method)

$\mathcal{B}(B \to e\nu) < 3.5 \times 10^{-6} (90\% C.L.)$

$\mathcal{B}(B \to \mu\nu) < 2.5 \times 10^{-6} (90\% C.L.)$

	e	μ
$N_{\text{expected BG}}$	$0.11^{+0.75}_{-0.06}$	$0.33^{+0.10}_{-0.08}$
ϵ_{signal}	$[9.1 \pm 1.5] \times 10^{-4}$	$[1.15 \pm 0.18] \times 10^{-3}$
$N_{\text{data observed}}$	0	0