Vub experimental measurement and theoretical interpretation

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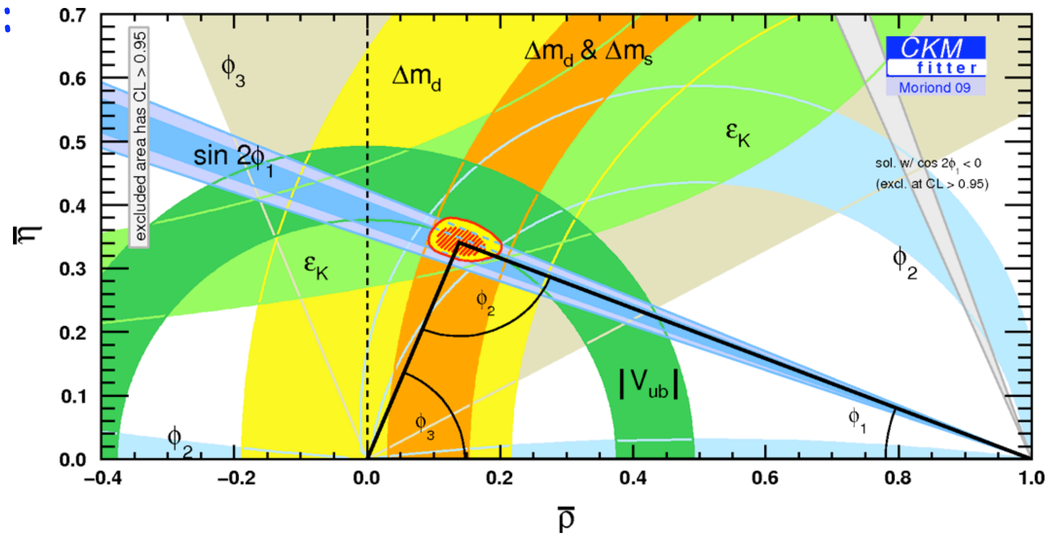
Introduction

CKM matrix elements are fundamental parameter of the Standard Model and cannot be predicted

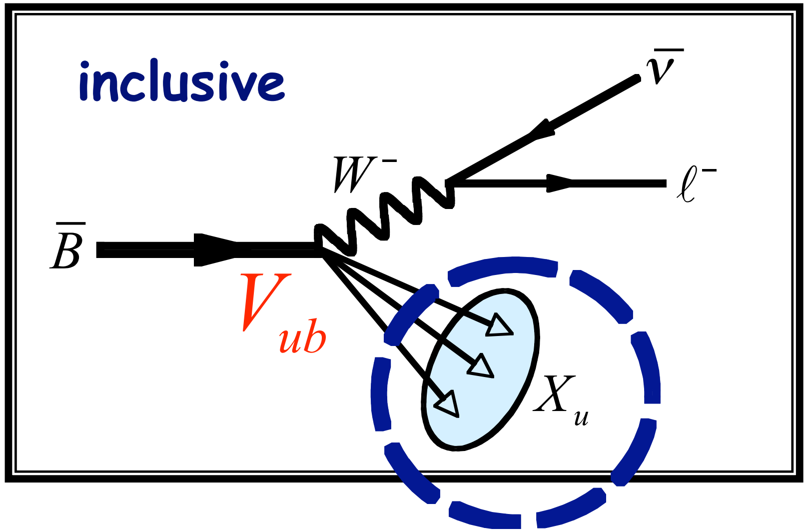
- exploit the unitarity constraint to look for new physics → geometrical relation between CKM elements:
  - ★ angle from CP asymmetries
  - ★ size from V

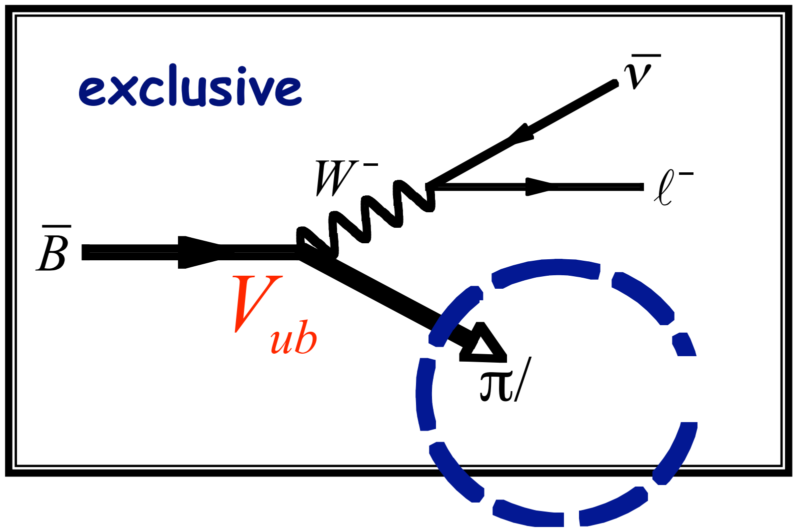


- New precision era where new physics may appear as a few percent disagreement: large new physics contributions to penguins would have already been seen.

- We must make the green ring thinner → uncertainty dominated by $|V_{ub}|$

V_{ub} determination



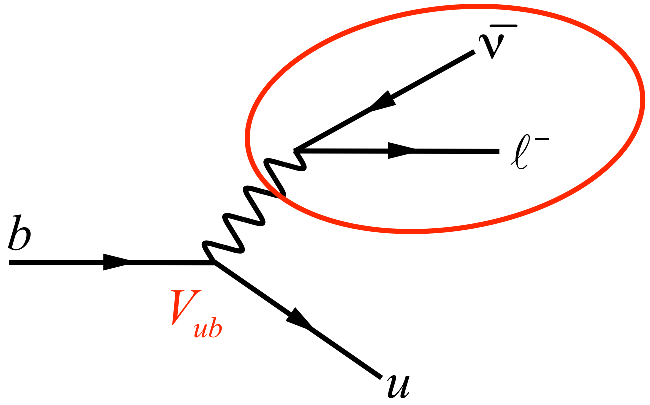


Theory errors dominates: measurements with different methods

- Inclusive $B \to X_u \ell \nu$
  - Use difference in kinematics to separate $u \ell \nu$ from $c \ell \nu$
  - Theory must predict signal spectrum
- Exclusive mainly $B \to \pi \ell \nu$
  - Better Signal/Noise
  - Theory must predict form factor

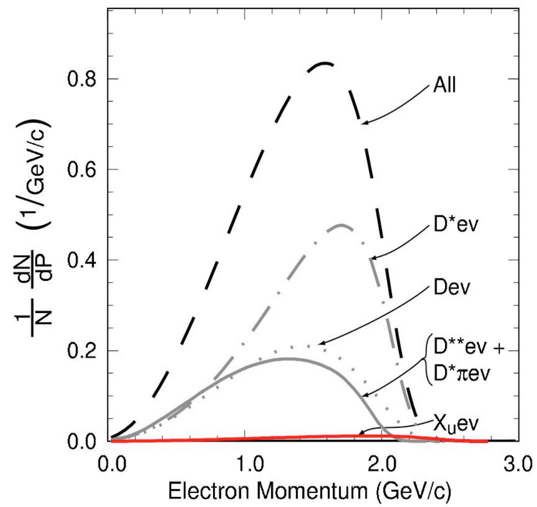
V_{ub} inclusive determination

$B \to X_u l \nu$ rate is very small, V_{ub} is small, therefore very difficult to measure



Tree level

$$\Gamma(b \to u \ell^- \bar{\nu}) = \frac{G_F^2}{192\pi^2} |V_{ub}|^2 m_b^5$$



the problem is the $b \to c l \nu$ decay

$$\frac{\Gamma(b \to u \ell \bar{\nu})}{\Gamma(b \to c \ell \bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

Selection to remove background removes a sizeble part of the phase space.

Need theoretical extrapolation for the full phase space

V_{ub} inclusive determination

- Cut away $b \to c l \nu$ $\Rightarrow$ lose a part of the $b \to u l \nu$ signal
  - We measure $\Gamma(B \to X_u \ell \nu) \times f_C = |V_{ub}|^2 \zeta_C$

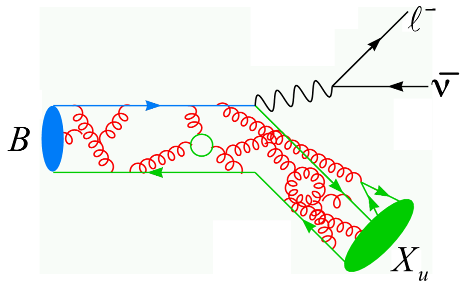
Total $b \to ulv$

Cut-dependent constant predicted by theory

Fraction of the signal surviving: need knowledge of b quark's motion inside B meson

★ Must be corrected for QCD

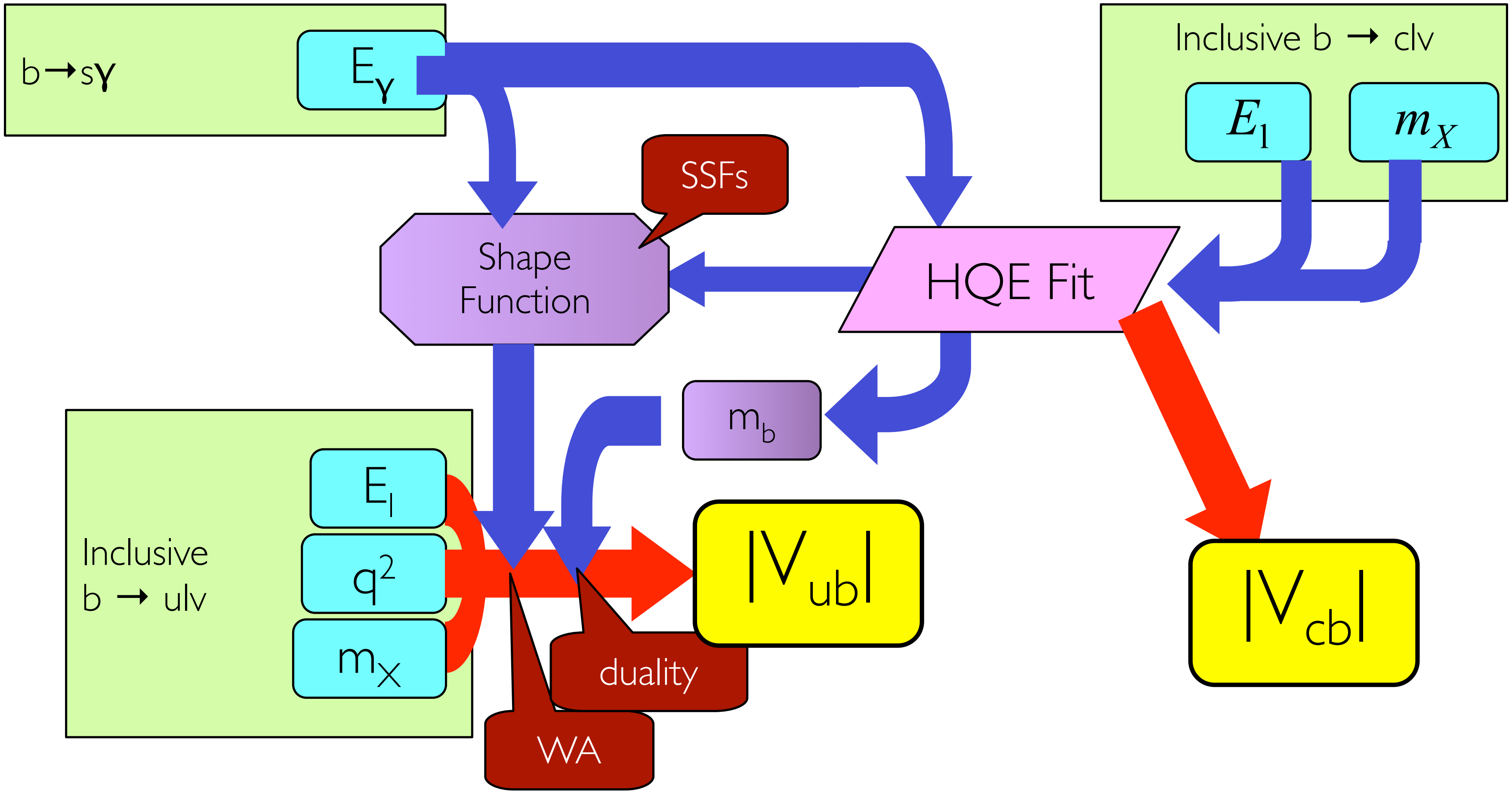
$$\Gamma(B \to X_u \ell \nu) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}\left[1 - O\left(\frac{\alpha_s}{\pi}\right) - \frac{9\lambda_2 - \lambda_1}{2m_b^2} + \cdots\right]$$



In principle the main uncertainty is from m_b^5 but we need a reasonable fraction (e.g., E_ℓ > 2 GeV) of the phase space.

How Things Mesh Together

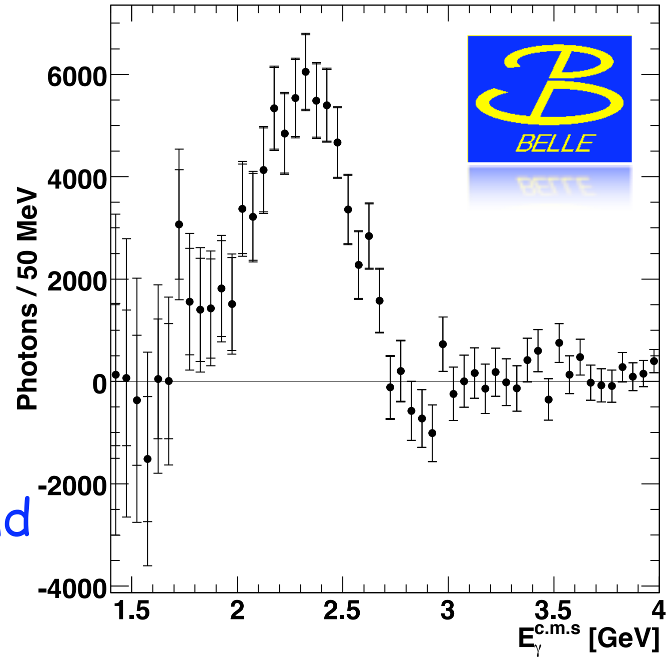
AKA: M. Morii's HQE plumbing diagram



Shape Function

Limited phase space to reduce the B $X_c l \nu$ background:

non-perturbative Shape Function to extrapolate to the full phase space



Detailed shape not constrained:

- ★ Fit the b → s γ spectrum to constrain the shape function
- ★ b-quark: mass and kinetic energy from b → clν and b → s γ decays
- ★ Plug the SF into the b → ulν spectrum calculations

Shape Function needs to be determined from experimental data.

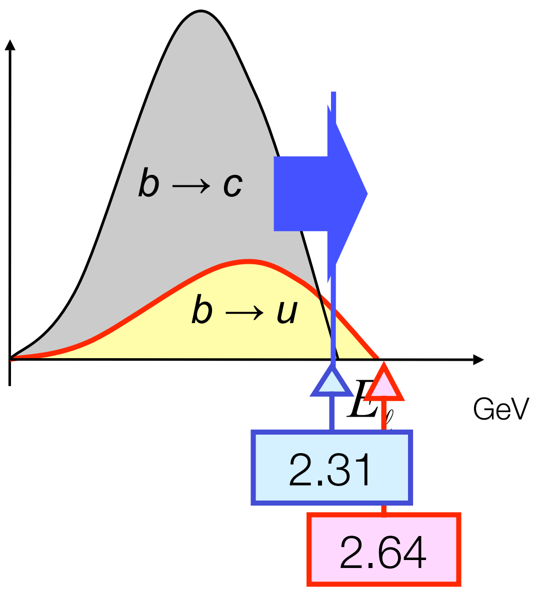
alternatives: cut out SF region, or factorise out the SF

Endpoint method

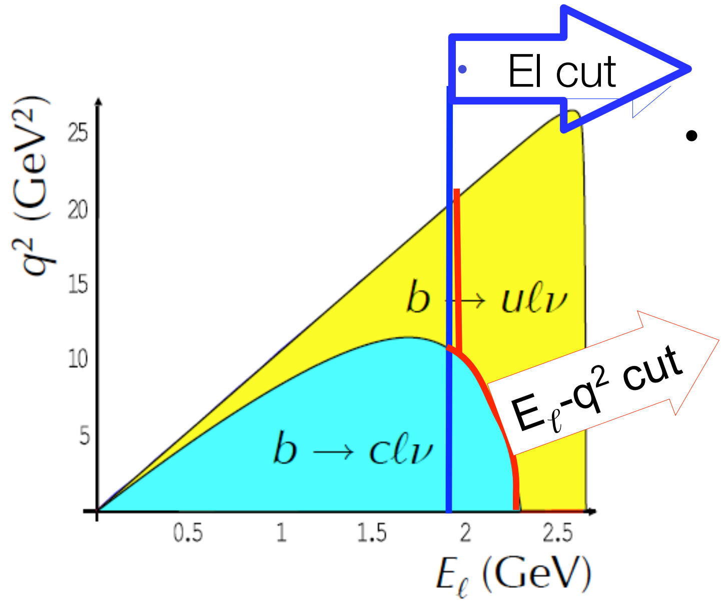
Use $m_u \ll m_c$ difference in kinematics

- ★ Maximum lepton energy 2.64 vs. 2.31 GeV
- ★ First observations by CLEO (1990) used this technique

Only 6% of signal accessible

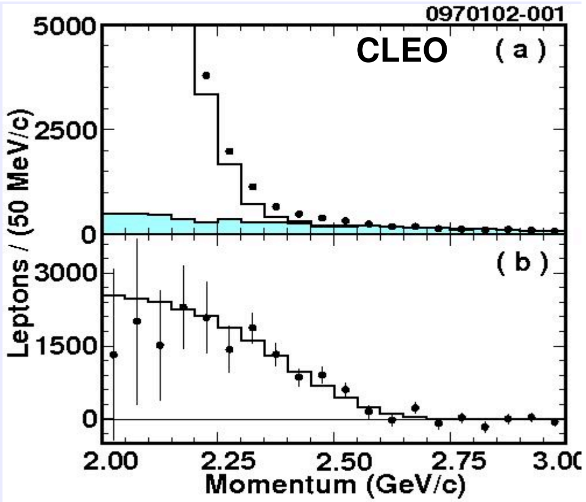


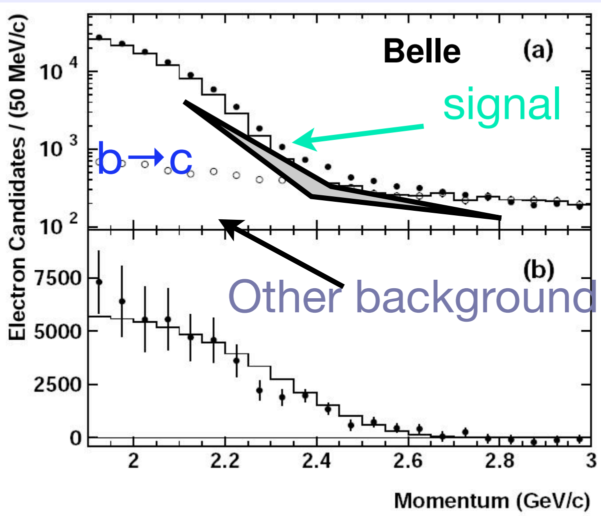
- ★ Small theory error requires low E_{lepton} cut
- ★ Small BG uncertainty requires high E_{lepton} cut

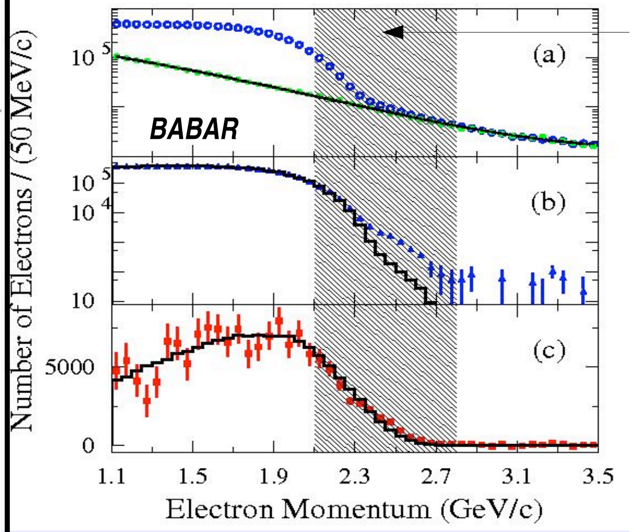


Measure partial BR in a region where S/N is acceptable and the width is reliably calculable.

Endpoint method







Subtract off-peak data scaled to on-peak luminosity bin-by-bin.

Fit MC to data in low energy region to constrain B->X_clν from data.

B→X_ulν, B→Dlν+B→D*lν (ratio fixed)
B→D**lν, B→$D^{(*)}$πlν (Goity & Roberts)

B→X_ulν, B→Dlν+B→D*lν (D/D* fixed)
B→D**lν D**/D+D* fitted ((D_1+D_2)/D** fixed)

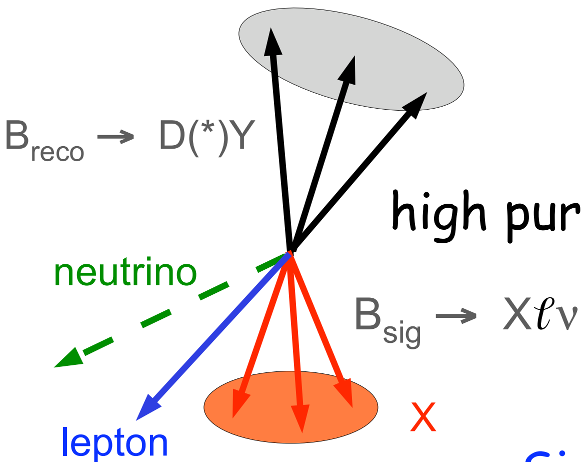
Simultaneous fit for non-BB̄, B→X_ulν, B→Dlν,
B→D*lν, B→D**lν, B→$D^{(*)}$πlν, other BG

		ΔBR × 10^{-4}	$\|V_{ub}\|$ × 10^{-3} %Δ(exp -the. + the.)
PRL 88, 231803, 2002	Belle 27fb^{-1}:E_e>1.9 GeV	8.47 ± 0.37_{stat} ± 1.53_{sys}	4.61(1±9.3 + 5.0 - 6.7)
PLB621, 28, 2005	BaBar: E_e > 2.0 GeV	5.72 ± 0.41(stat±0.65(syst)	4.13(1±5.6 + 5.6 - 8.2)
PRD 73, 012006, 2006	CLEO: Ee > 2.0 GeV	4.22 ± 0.33_{stat} ± 1.78_{sys}	3.77(1±12. + 6.9 - 10.)

Inclusive: fully reconstructed sample

Best access to kinematics with B meson "beam"

tag: charge and momentum

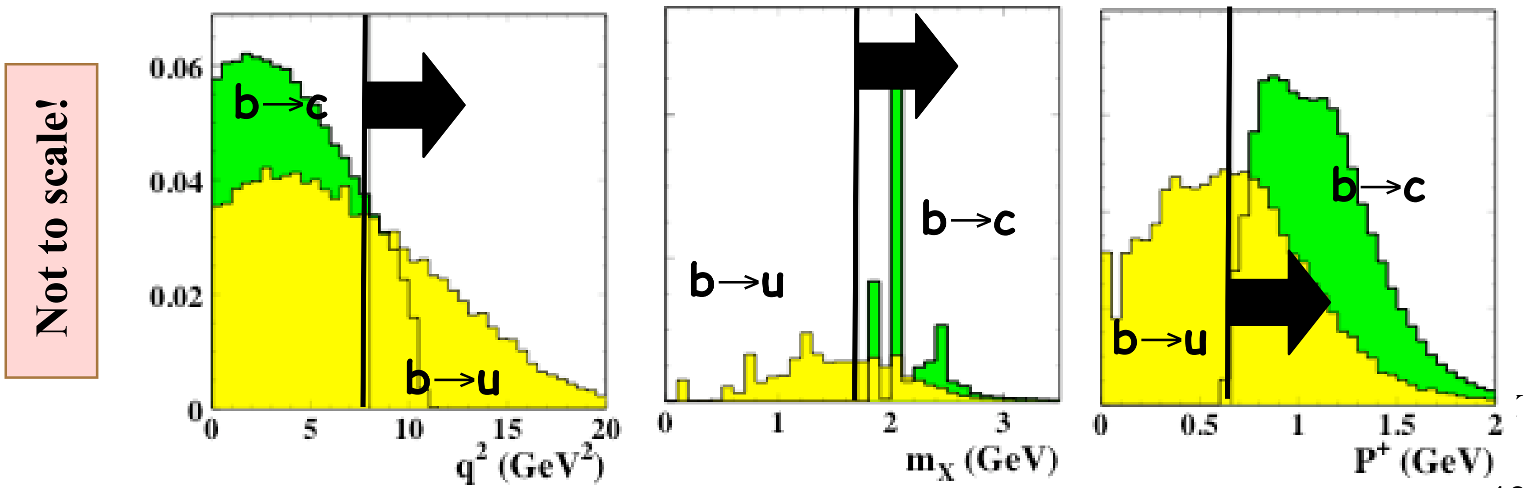


high purity, low efficiency

$m_u \ll m_c \rightarrow$ difference in kinematics

q^2 =	lepton-neutrino mass squared
m_X =	hadron system mass
P^+ =	$E_X - \lvert P_X \rvert$

Signal events have smaller M_X and P_+ $\rightarrow$ Larger E_l and q^2



Relative branching fractions

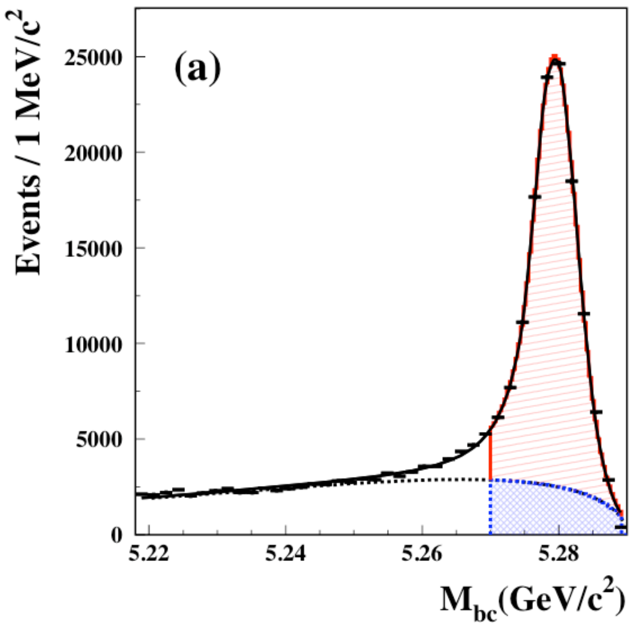
Signal side:

Reconstruct high momentum lepton

No strangeness

Event Level:

$\Sigma Q=0$, $Q_{Breco} \times Q_l = -1$, M_{miss}, etc.



- ★ Fit M_{bc} in bins of P_+, M_X, q^2
- ★ Fit to P_+, M_X, q^2 with various background and signal floated to determine background yield.
- ★ Relative BR to control systematics

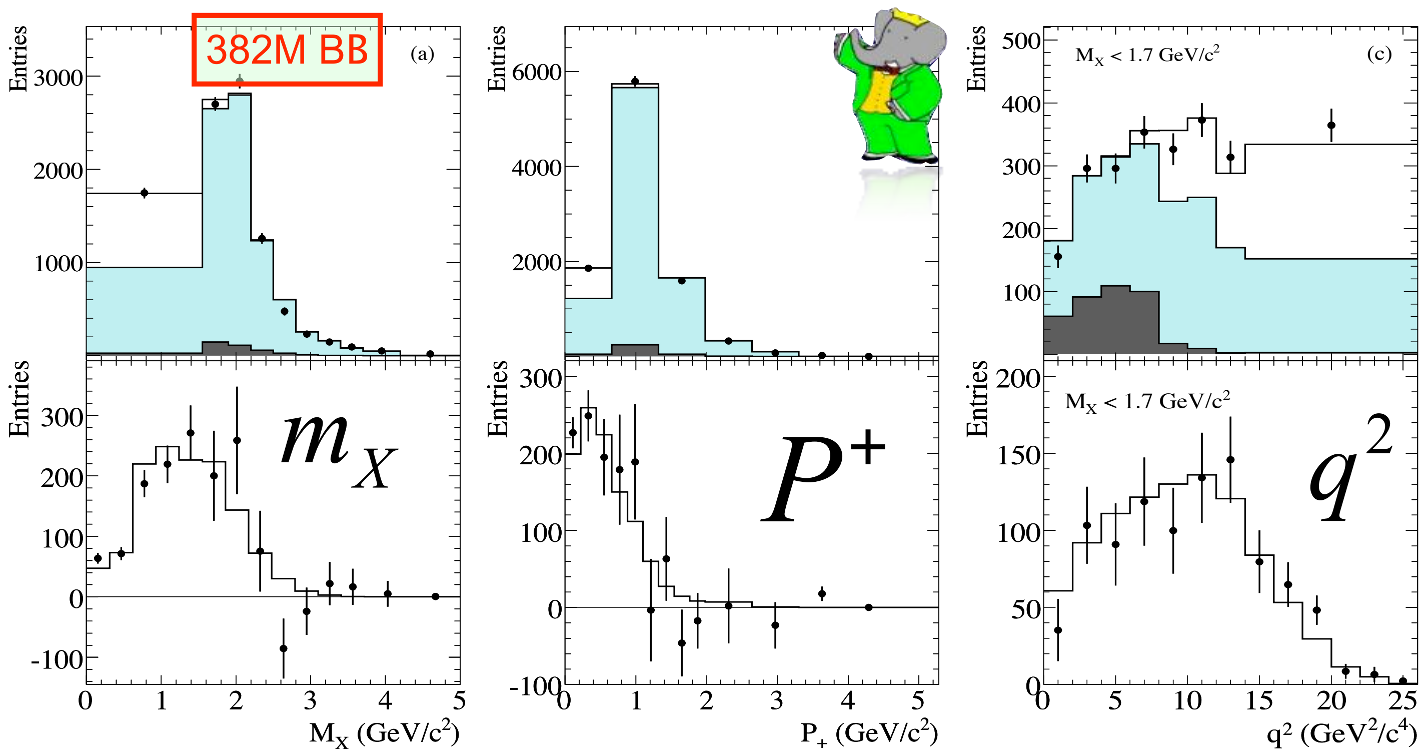
e.g. BELLE

$$\frac{\Delta Br(X_u l \nu)}{Br(X l \nu)} = \frac{N_{b\to u}}{N_{sl}} \cdot \frac{F}{\varepsilon_{sel}} \cdot \frac{\varepsilon_{frec}^{b\to u}}{\varepsilon_{frec}^{sl}} \frac{\varepsilon_{\ell}^{b\to u}}{\varepsilon_{\ell}^{sl}}$$

- PDG: $Br(X l \nu)$
- Number of excess events: $N_{b\to u}$
- Number of semileptonic events: N_{sl}
- Unfolding factor F
- selection efficiency: ε_{sel}
- Ratio of efficiencies for $b\to u$ and sl

Inclusive V_{ub}

- $B \to X_u l n$
- $B \to X_c l n$
- $B \to X_u l n$ outside selected region



Kinematic Region	$B(B \to X_u l \nu) \times 10^{-3}$ Δ(stat. sys. th.)	$\lvert V_{ub} \rvert\ (10^{-3})$ Δ(stat. sys. th.)	Theory
M_X<1.55 GeV	1.18 ± 0.09 ± 0.07 ± 0.01	4.27 ± 0.16 ± 0.13 ± 0.30	BLNP
		4.56 ± 0.17 ±0.14 ± 0.32	DGE
P_+<0.66 GeV	0.95 ± 0.10 ± 0.08 ± 0.01	3.88 ± 0.19 ± 0.16 ± 0.28	BLNP
		3.99 ± 0.20 ± 0.16 ± 0.24	DGE
M_X<1.7 GeV & q^2>8.0 GeV^2	0.76 ± 0.08 ± 0.07 ± 0.02	4.48 ± 0.22 ± 0.19 ± 0.30	BLNP
		4.53 ± 0.22 ± 0.19 ± 0.25	DGE
		4.81 ± 0.23 ± 0.20 ± 0.36	BLL

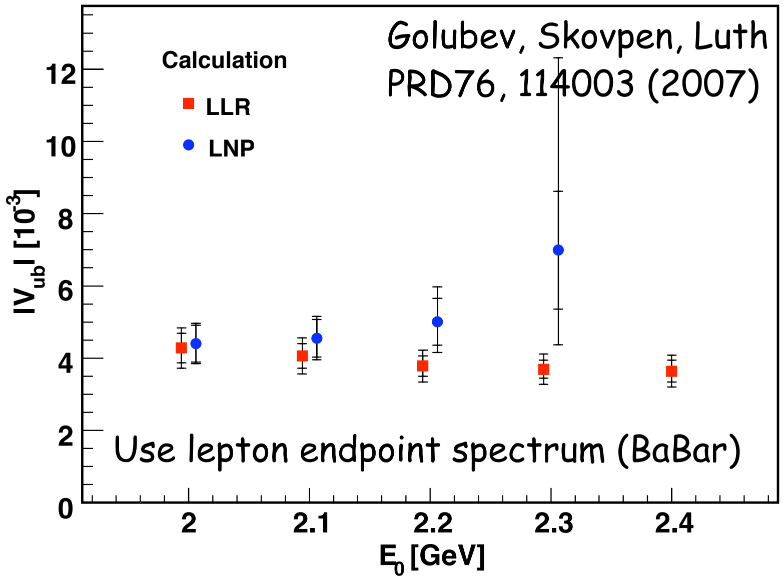
SF independent analyses

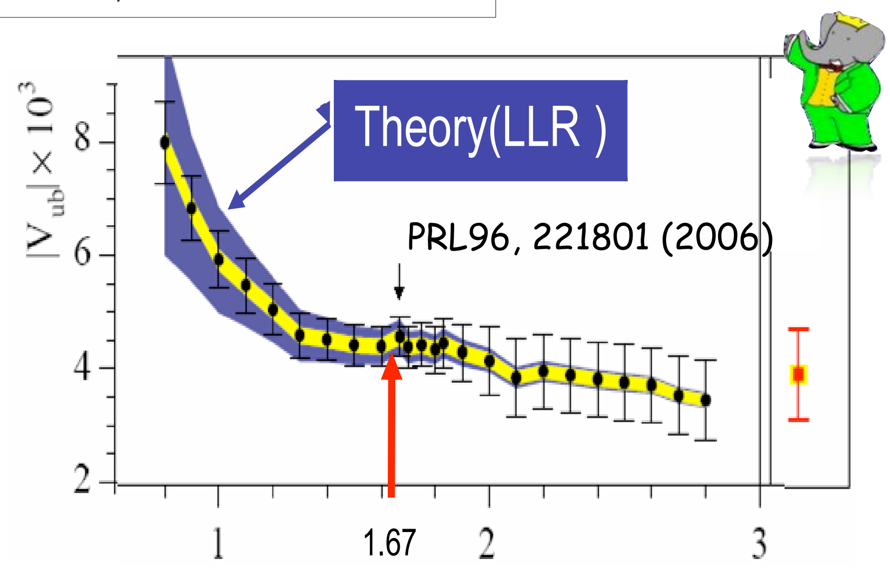
Exploit the assumption that the leading shape functions are the same for all b→q transitions.

LNP Lange,Neuber,Paz JHEP0510:084 (2005)

LLR Leibovich,Low,Rothstein PRD61,053006(2000) PLB513,83 (2001)

$$\int_0^{m_{max}} \frac{d\Gamma(b\to u)}{dm_X}\,dm_X \Leftrightarrow \int_{E_{min}}^{m_B/2} \frac{d\Gamma(b\to s\gamma)}{dE_\gamma}\,W(E_\gamma, E_{min})\,dE_\gamma$$





M_X in Breco sample (89 fb^{-1})

$|V_{ub}|=(4.43 \pm 0.30_{stat} \pm 0.25_{syst} \pm 0.29_{theo})\times 10^{-3}$

Uncertainties due to non-perturbative power corrections increase rapidly near the kinematic end point (not included in LLR).
Results agree with analyses that rely on assumed shape function form.

Inclusive $|V_{ub}|$

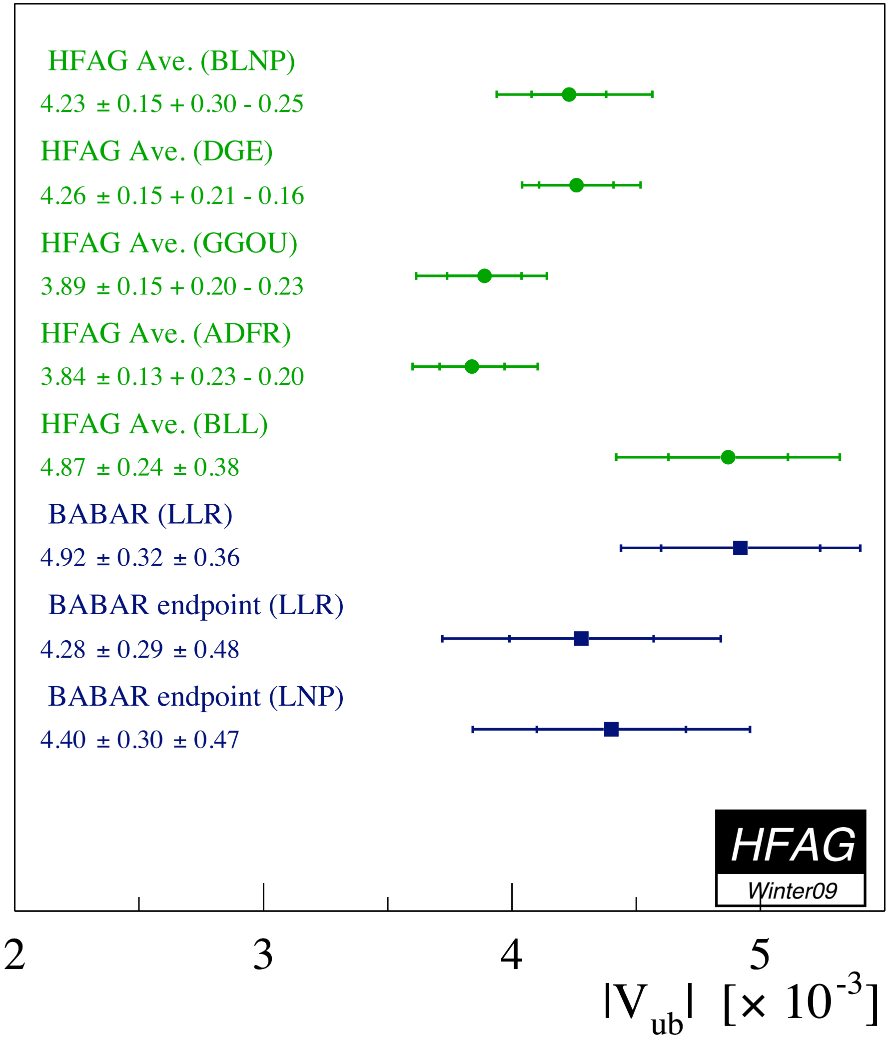
OPE based + SF

- BLNP: HQE with systematic introduction of SF (PRD71:073006 (2005))
- BLL: phase space in m_X-q^2 with reduced SF (PRD64:113004 (2001))
- GGOU: kinetic scheme (JHEP 10(2007) 058)
- LNP (LLR): $b \to s\gamma$ directly related to $b \to ul\nu$ (JHEP 0510:084 (PLB 486:86))

No SF introduced ➢ model non-perturbative QCD

- DGE: Dressed Gluon Exponentiation (JHEP 0601:097 (2006))
- ADFR: Analytic coupling (PRD74:03400(4,5,6) (2006))

Different $|V_{ub}|$ values from different calculations



all determinations moved of ~-1 x10^{-4} from ICHEP08 due to m_b change

Theory errors

BLNP as example

Weak annihilation 1.5% error

Expected <2% of the total rate: potential problem for all inclusive determinations which include large q^2 region (M. Voloshin, hep-ph/0106040)

Reduce the effect by rejecting the high-q^2 region

Subleading Shape Function 1.8% error

Higher order non-perturbative corrections, matching

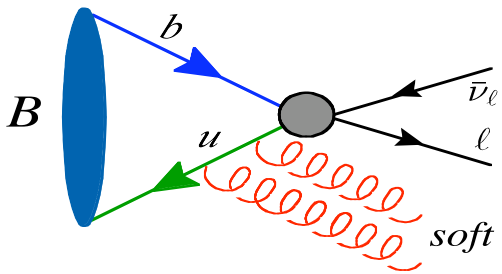
HQ parameters 5.3% error

Mainly m_b: kinematic cuts which give a higher m_b, dependence e.g. for end-point $\sim m_b^{11}$

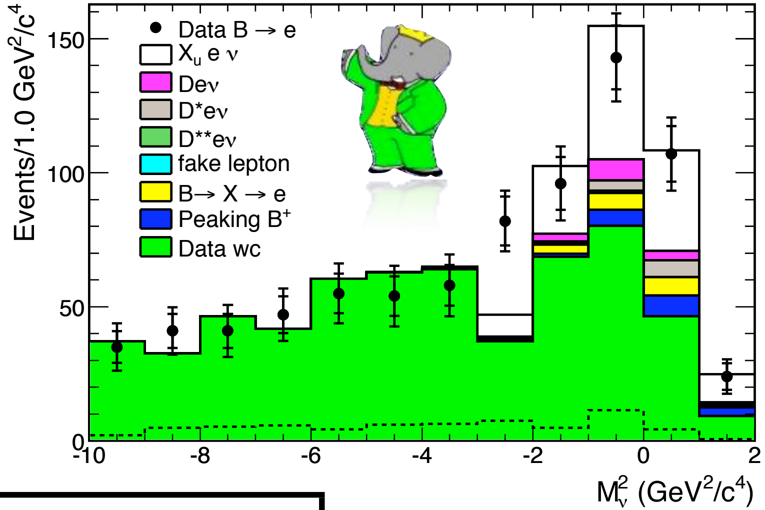
No uncertainty is assigned for possible duality violations.

Weak anihilation

Different BR between B^+ and B^0: compare B^0 partial rate to B averaged rate to enhance the WA contribution
(PRD73, 012006 (2006))



$$\frac{|\Gamma_{WA}|}{.\Gamma_u} < 7.4\% \ at \ 90\% C.L.$$ *CLEO, studing the q^2 spectra PRL96,121801 (2006)*



$$\frac{|\Gamma_{WA}|}{\Gamma_u} < \frac{3.8\%}{f_{WA}(2.3-2.6)} \ at \ 90\% C.L.$$

arXiv: 0708.1753 383 M BB

Δp (GeV)	ΔB(B) 10^4	ΔB(B^0) 10^4	$A^{+/0}$
2.3-2.6	2.31±0.10±0.18	1.30±0.21±0.07	0.08±0.15±0.08
2.4-2.6	0.75±0.04±0.06	0.76±0.15±0.05	-0.05±0.20±0.10

Inclusive $|V_{ub}|$

604 fb^{-1}

Belle 09 submitted to PRL

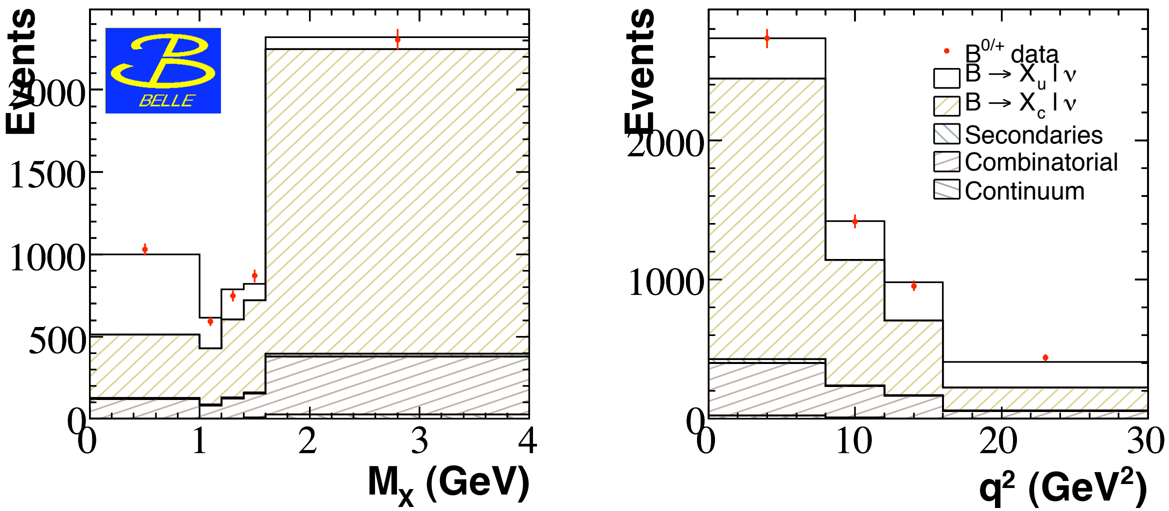
Irreducible uncertainties for V_{ub} are related to limited phase space.

Fully reconstructed sample signal and lepton with $p_{lep}^{B*} > 1$ GeV

Boosted Decision Tree with many input: M_{miss}^2, Q_{total}, Q_{lepton}, N_{lepton}, D^* partial reco etc.....

Combinatorial estimated from MC, normalisation from sideband region.

2D fit to M_x, q^2 with backgrounds and signal floated to get background yield.



$p_{lep}^{B*} > 1$ GeV

Main systematics: inclusive V_{ub} model 3.9% and exclusive V_{ub} model 3.9% (5.5% total)

Inclusive $|V_{ub}|$

New Belle analysis

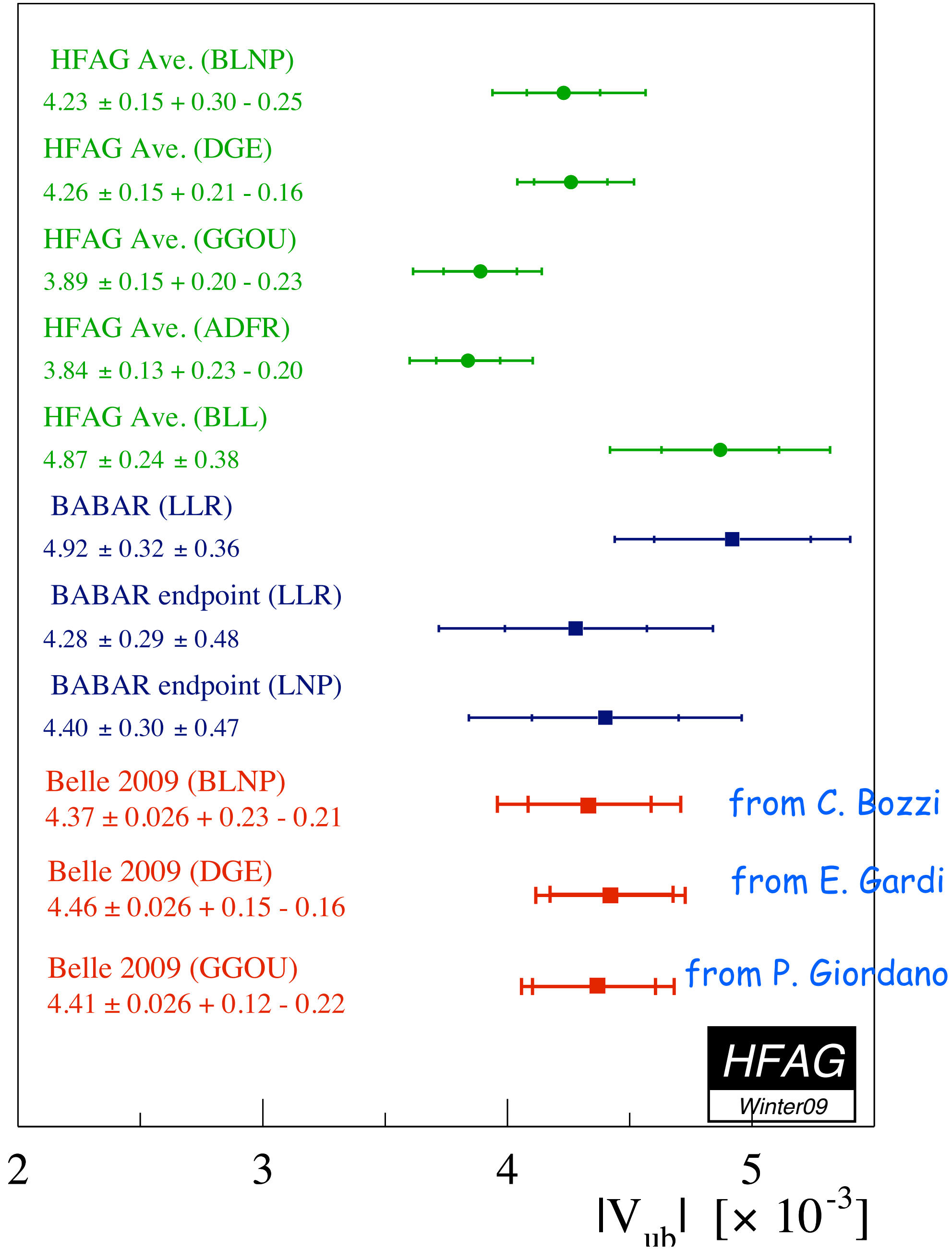
Measure absolute rate:

ΔB ($B \to X_u l \nu$: p^{*B}_l >1.0 GeV/c) =

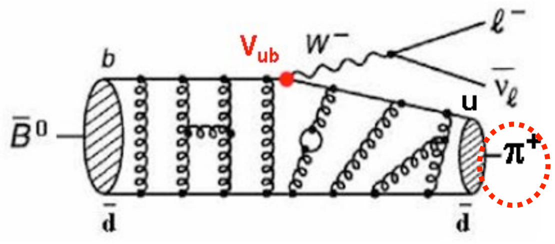
1.963(1 ± 0.088 (stat.) ± 0.081 (sys.))$\cdot 10^{-3}$

Theoretical error smaller than the world average mainly due to a small power dependence on m_b

~90% total phase space, thus theory error less correlated to other V_{ub} determinations



Exclusive $|V_{ub}|$



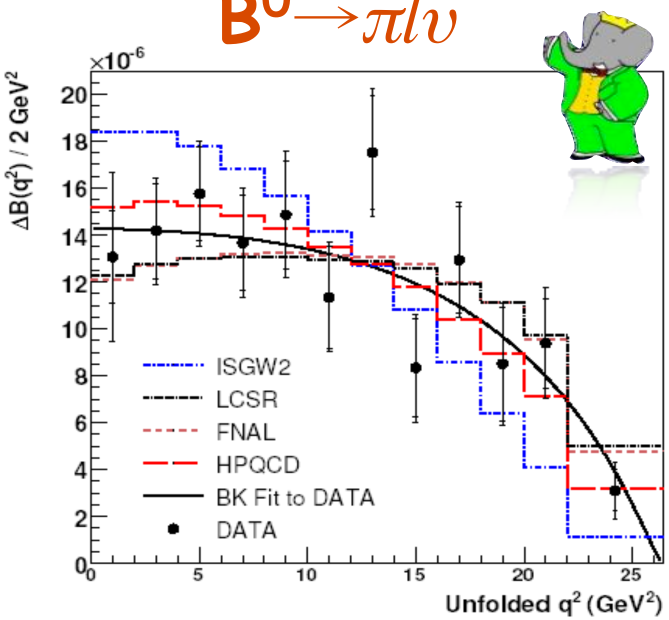
Experimentally clean

Currently only $B \to \pi l \nu$ for $|V_{ub}|$

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

form factor: q^2 shape and normalization needed

$B^0 \to \pi l \nu$



Phys.Rev.Lett. 98 (2007) 091801

Form factor calculations from various methods:

- "unquenched" lattice QCD (HPQCD, Fermilab, ...)
- Light-Cone Sum Rules (Ball & Zwicky, ...)
- quark models (ISGW2, ...)

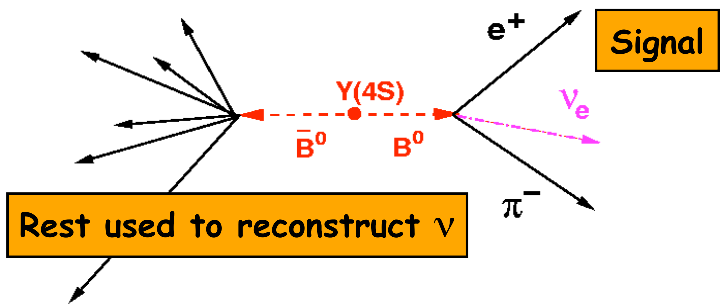
LQCD and LCSR compatible with data ISGW2 quark-model incompatible (Prob<0.06%).

Approaches to Measuring $B(B \to X_u\, l\, \nu)$ Exclusive

Untagged

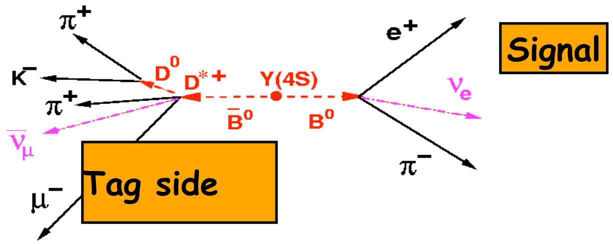
- Initial 4-momentum known.
- Missing 4-momentum = ν .
- Reconstruct $B \to X_u\, l\, \nu$

using m_B (beam-constrained) and $\Delta E = E_B - E_{beam}$.



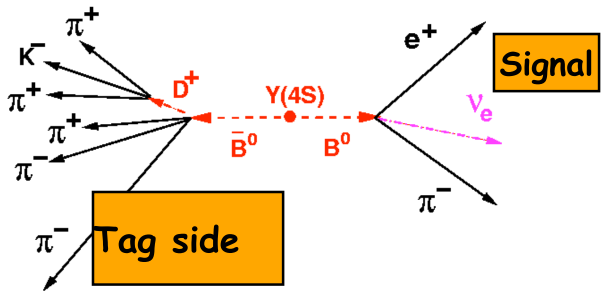
Semileptonic Tag

- One B reconstructed in a selection of $D^{(*)}\, l\, \nu$ modes.
- Two missing ν s in event.
- Use kinematic constraints.



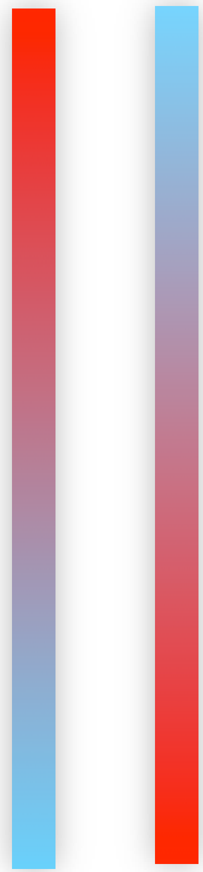
Full Reconstruction Tag

- One B reconstructed completely in known $b \to c$ mode.



E. Barberio

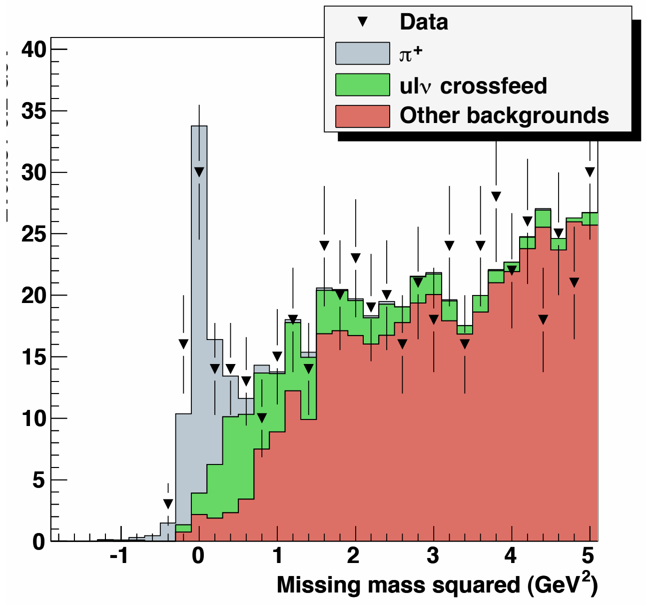
Effi.	Purity	Lumi.
High	Low	
		< 0.5ab^{-1}
		< 1 ab^{-1}
		> 1ab^{-1}
Low	High	

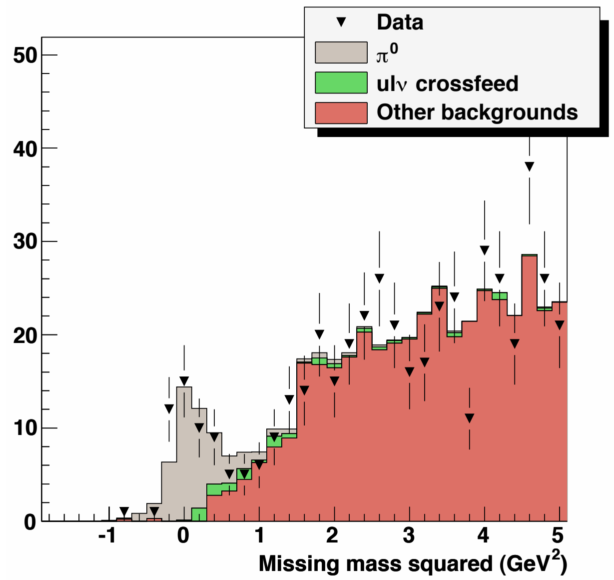


Exclusive V_{ub}

hep-ex 0812.12214

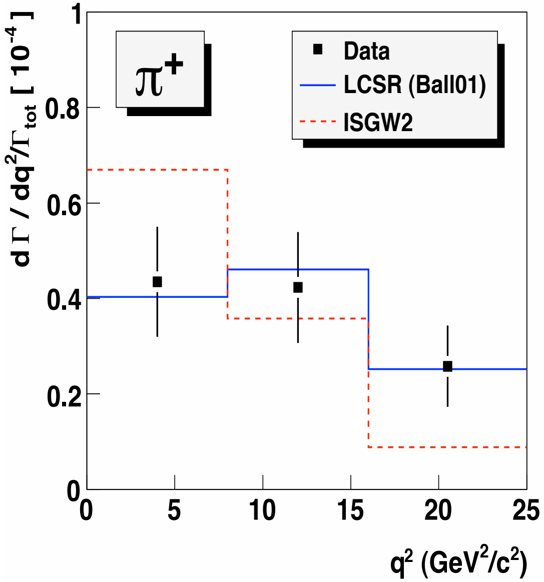
604 M BB

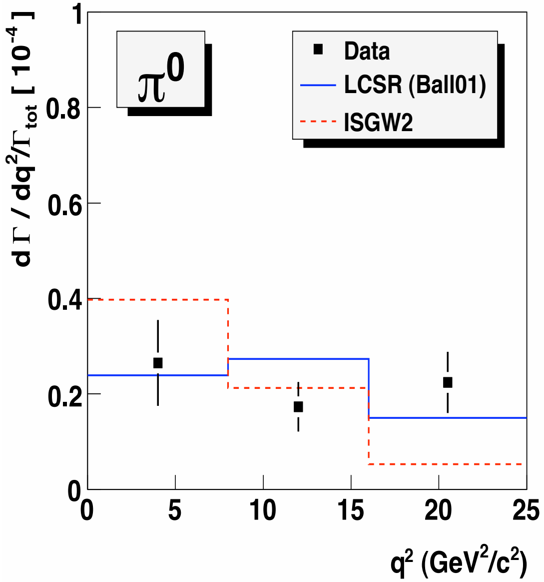




Fully reconstruct the B_{reco}: Know kinematics and flavor of signal B

Signal yields from $M^2_{miss} \approx M^2_{\nu}$ distribution in 3 q^2 bins

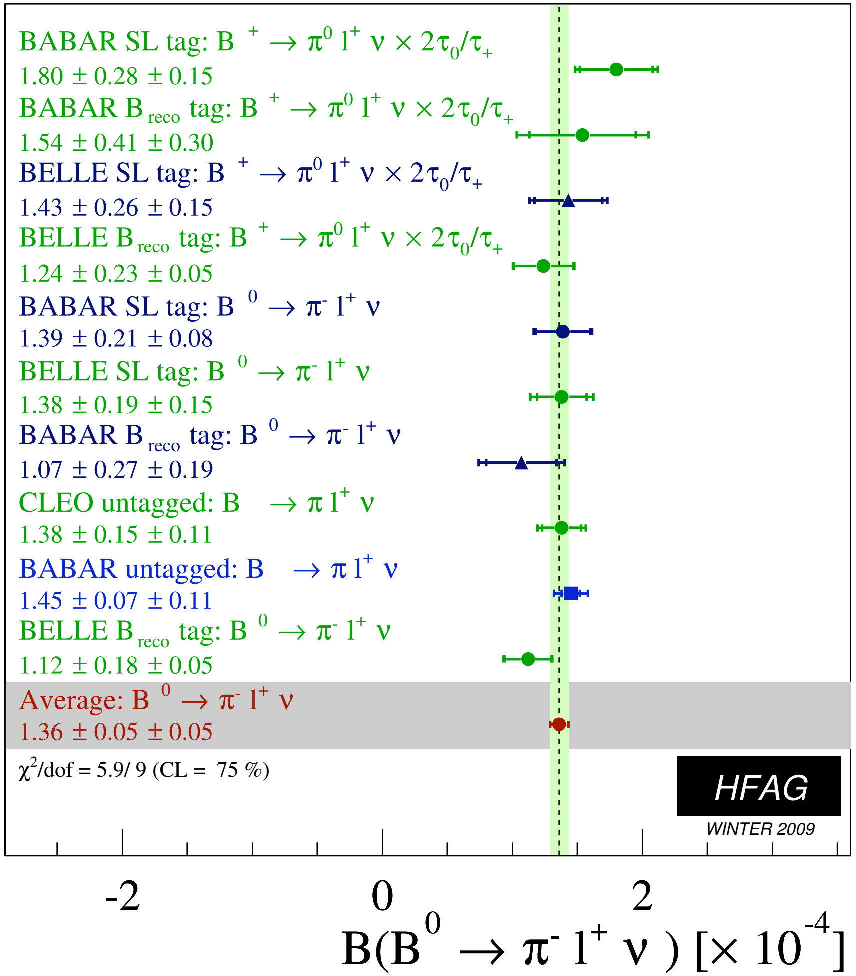


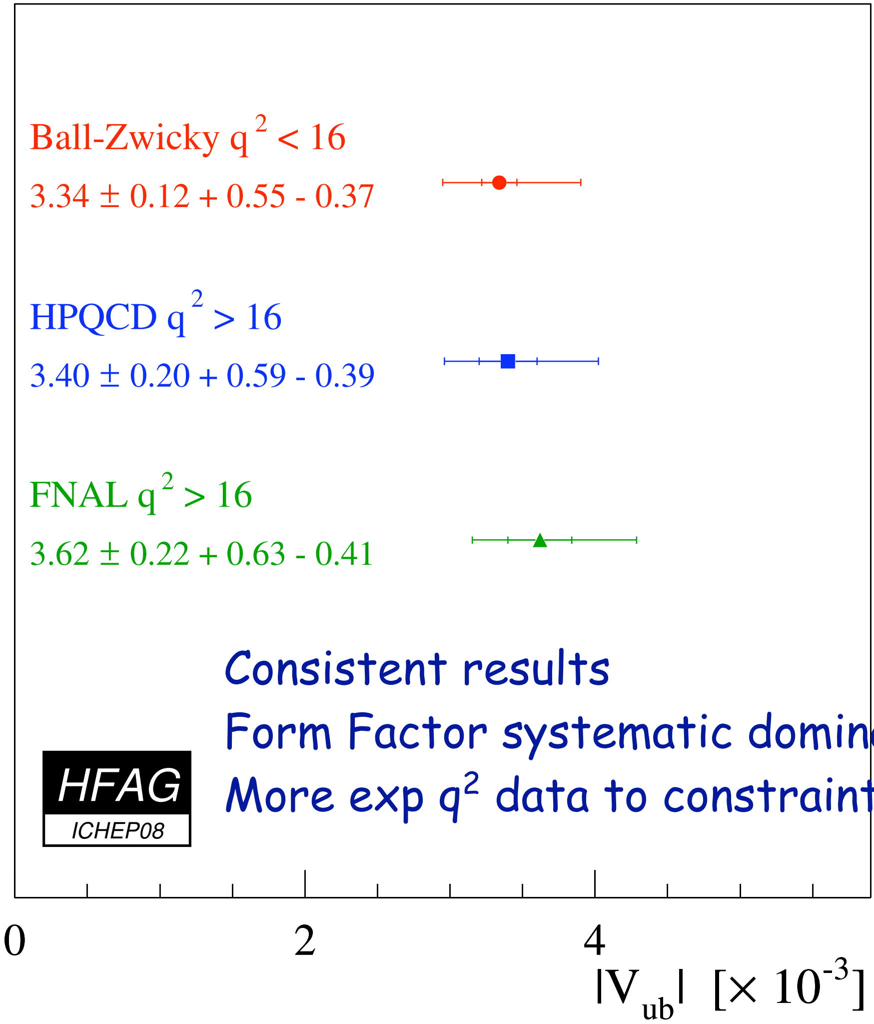


$$\Delta\mathcal{B}\left(B \rightarrow \pi\ell\nu\right)_{q^2<16\ GeV^2} = (0.82 \pm 0.12 \pm 0.04) \times 10^{-4}$$

$$\Delta\mathcal{B}\left(B \rightarrow \pi\ell\nu\right)_{q^2>16\ GeV^2} = (0.31 \pm 0.07 \pm 0.02) \times 10^{-4}$$

Current status of Br($B^0 \to \pi^- l^+ \nu$) & $|V_{ub}|$



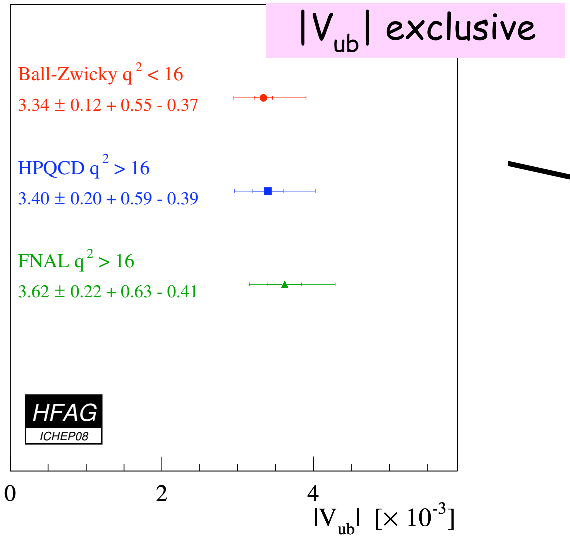


Consistent results

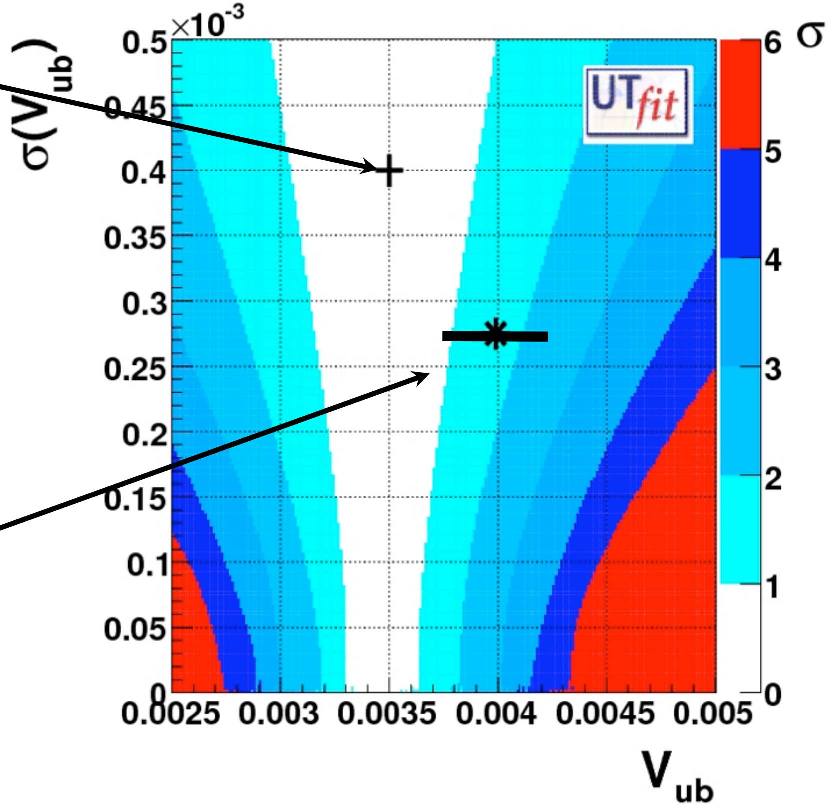
Form Factor systematic dominates

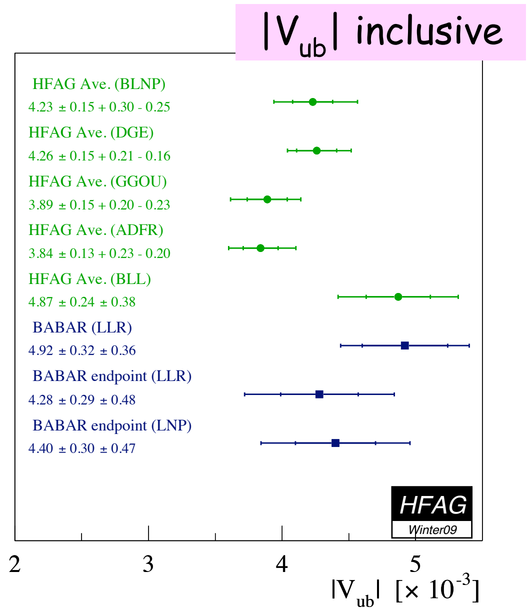
More exp q^2 data to constraint FF

$|V_{ub}|$: inclusive vs exclusive



Most probable value of V_{ub} from measurements from other CKM parameters





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CONCLUSION AND OUTLOOK

Inclusive V_{ub} ~6-7% with the theoretical error is dominated by the extrapolation to the unmeasured phase space

The new Belle measurement alone has ~7% error and covers 90% of phase space : all the extraction frameworks used are in good agreement

Exclusive: the error is coming down, it is the way to go in the future (super b-factories)

The inclusive vs exclusive: the gap is decreasing mainly due to the change in the value of m_b

m_b more in details

comparison from
A. Hoang
Vxb workshop 2007
Heidelberg

1S	m_b (GeV)
	4.70±0.03
no b→s γ	4.751±0.058

Kinetic	m_b (GeV)
	4.613±0.022+0.027 → $m^{1S} = 4.76$
no b→s γ	4.677±0.053 → $m^{1S} = 4.83$

	1S fit: b→s γ	1S fit: no b→s γ	Kin fit: b→s γ	Kin fit: no b→s γ
m^{1S}	4.70	4.75	4.76	4.83
$\overline{m}(\overline{m})$	4.18	4.22	4.23	4.30

$\overline{m}(\overline{m})_{PDG}$ = 4.20 ± 0.07 GeV

⋮

HFAG Winter09

1S	m_b (GeV)
	4.70±0.03

Kinetic	m_b (GeV)
	4.620±0.035
no b→s γ	4.678±0.051

New Belle Multivariate analysis

Measure absolute rate:

$\Delta B (B \to X_u l \nu : p^{*B}_l > 1.0\ GeV/c) = 1.963 \cdot (1 \pm 0.088\ (stat.) \pm 0.081\ (sys.)) \cdot 10^{-3}$

Scheme	HQE par.	$\lvert V_{ub}\rvert$
BLNP	$m_b(SF)=4.650^{+0.043}_{-0.037}$ GeV $\mu_\pi^2(kin)(SF)=0.256^{+0.057}_{-0.077}$ GeV^2	$4.37 \cdot (1 \pm 0.043(stat.) \pm 0.040(sys.)^{+0.031}_{-0.027}(m_b)^{+0.043}_{-0.040}(th.)) \cdot 10^{-3}$
DGE	$m_b(MSbar)=4.248 \pm 0.051$ GeV	$4.46 \cdot (1 \pm 0.043(stat.) \pm 0.040(sys.)^{+0.032}_{-0.033}(m_b)^{+0.010}_{-0.015}(th.)) \cdot 10^{-3}$
GGOU	$m_b(kin)=4.620 \pm 0.035$ GeV $\mu_\pi^2(kin)=0.424 \pm 0.042$ GeV^2/	$4.41 \cdot (1 \pm 0.043(stat.) \pm 0.040(sys.) \pm 0.019(m_b)^{+0.021}_{-0.045}(th.)) \cdot 10^{-3}$

19

Exclusive V_{ub}

arXiv:0805.2408 [hep-ex]

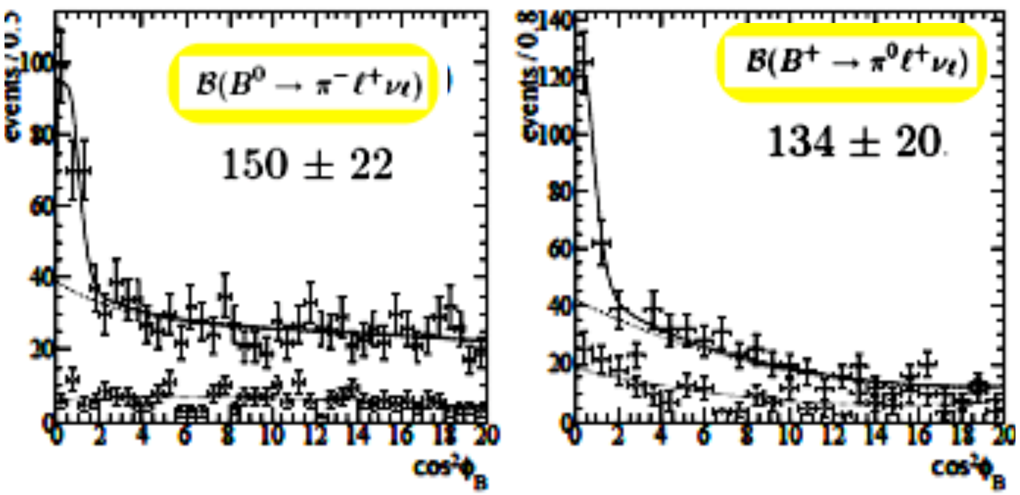
348 fb^{-1}

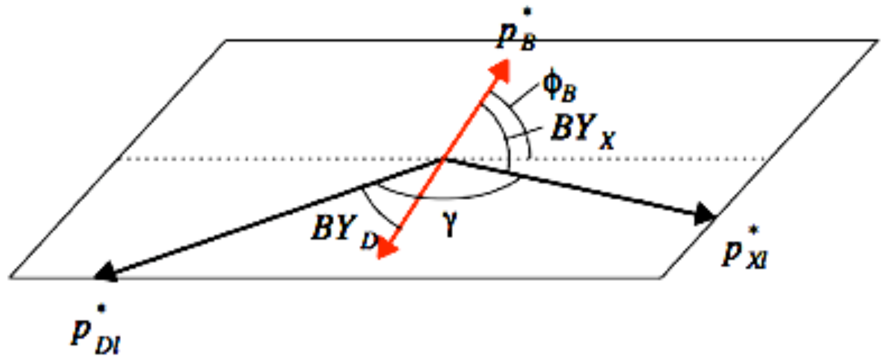
Semileptonic Tag

Tag one B in $D^{(*)} l \nu$ and look for signal in the recoil;

Identify a signal lepton and search for a π^+, π^-, π^0

Signal yields from unbinned maximum likelihood fit to $\cos^2 \varphi_B$.

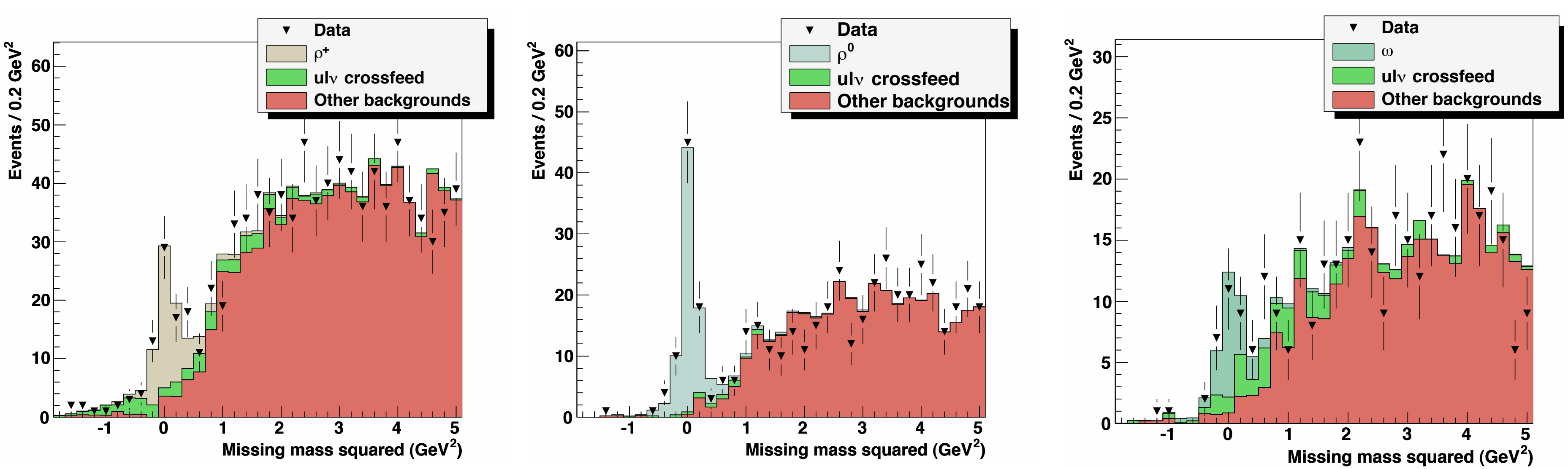




$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.38 \pm 0.21 \pm 0.07) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell) = (0.96 \pm 0.15 \pm 0.07) \times 10^{-4}$$

Full reconstruction



Mode	$\Delta\mathcal{B}\ [10^{-4}]$ $0 < q^2 < 8$ (GeV^2)	$8 < q^2 < 16$ (GeV^2)	$q^2 > 16$ (GeV^2)	$\mathcal{B}\ [10^{-4}]$ Sum (GeV^2)
$B \to \rho^+ \ell \nu$	$0.74 \pm 0.29 \pm 0.04$	$1.01 \pm 0.28 \pm 0.05$	$0.81 \pm 0.21 \pm 0.04$	$2.56 \pm 0.46 \pm 0.12$
$B \to \rho^0 \ell \nu$	$0.72 \pm 0.15 \pm 0.03$	$0.70 \pm 0.13 \pm 0.03$	$0.39 \pm 0.11 \pm 0.02$	$1.80 \pm 0.23 \pm 0.07$
$B \to \omega \ell \nu$	$0.23 \pm 0.17 \pm 0.01$	$0.64 \pm 0.21 \pm 0.03$	$0.32 \pm 0.17 \pm 0.01$	$1.19 \pm 0.32 \pm 0.05$