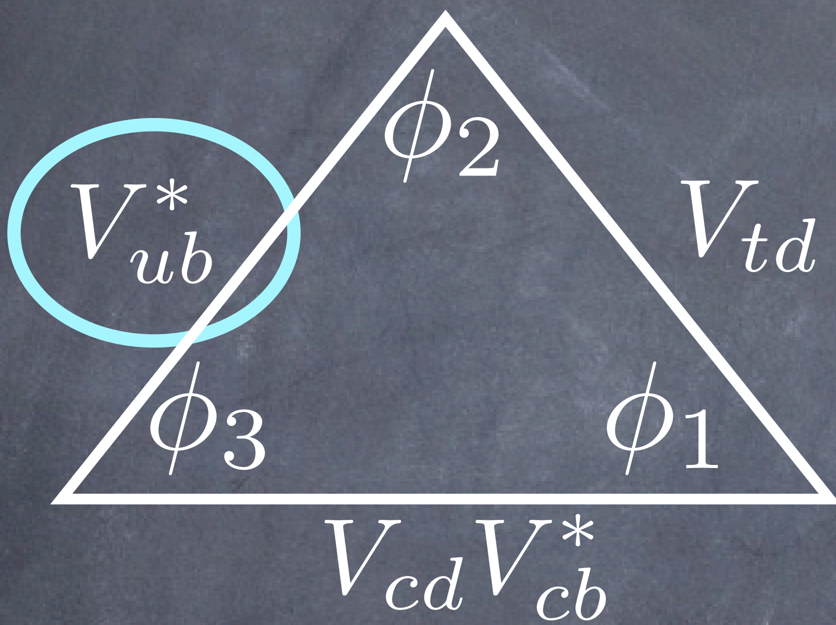
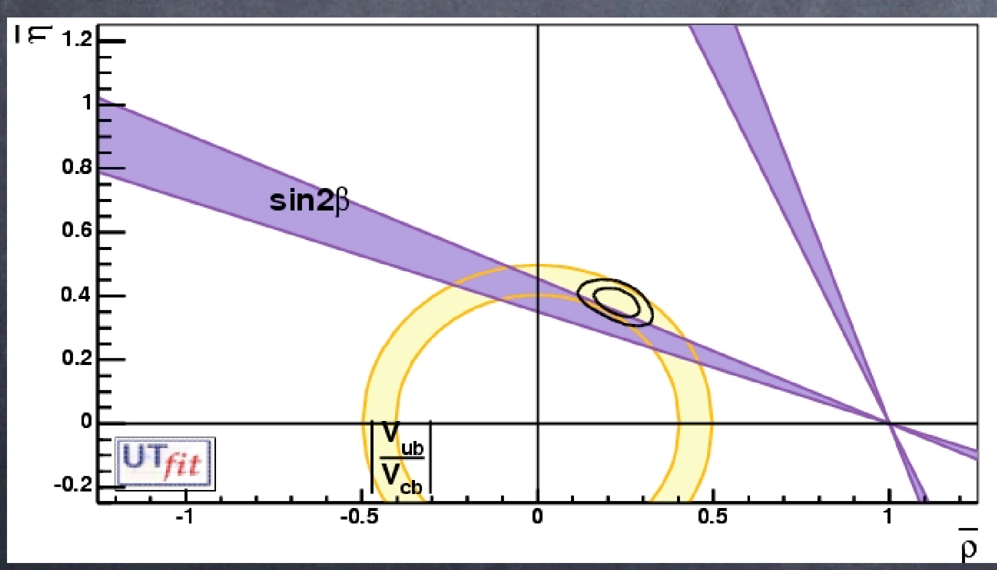
V_{ub} Experimental Results



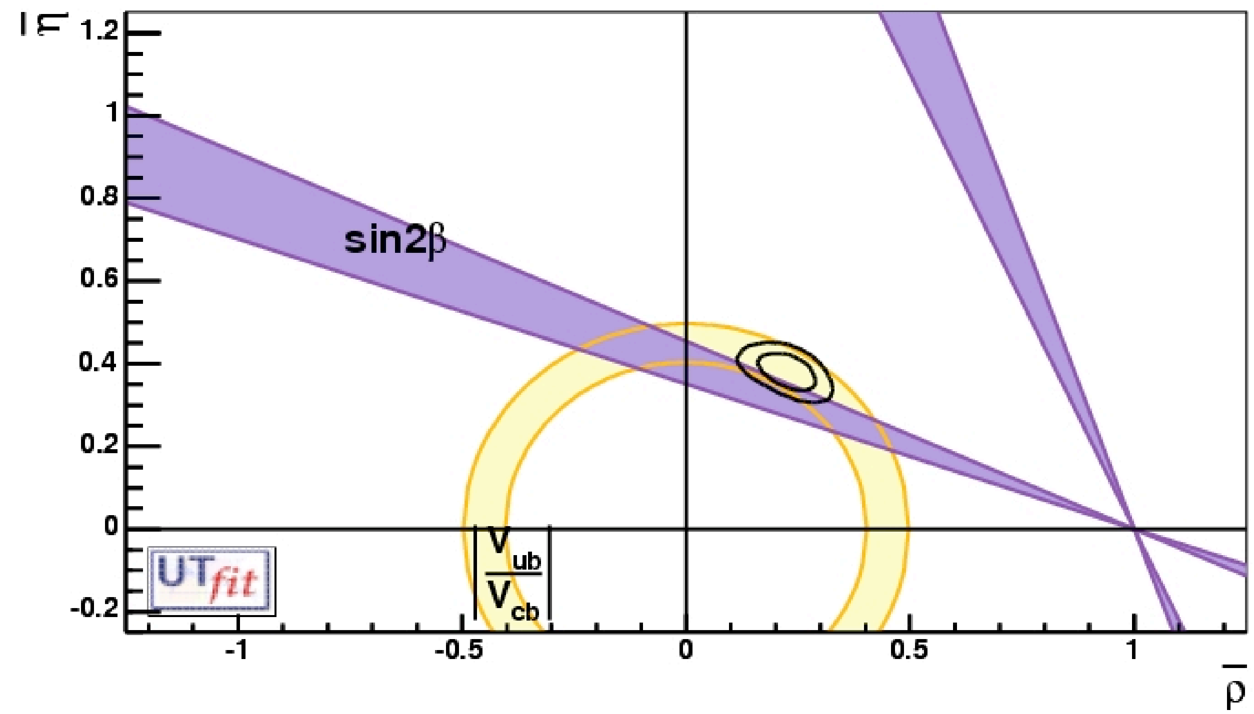


Youngjoon Kwon
Yonsei Univ. / Belle

- Motivation & basic issues
- Results
  - exclusive
  - inclusive
- Summary

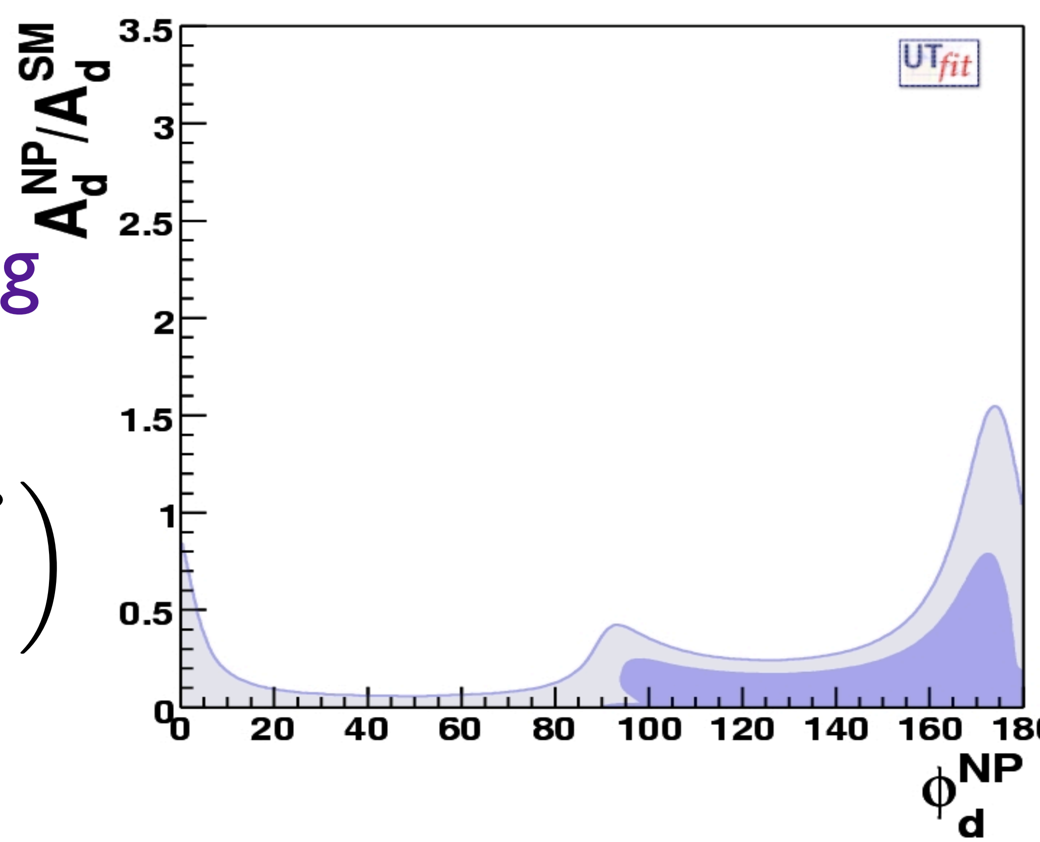
Motivations

- Non-zero Vub --> CP violation in B decays
- V_{ub} vs. $\sin(2\phi_1)$ --> strong constraint on UT.



Direct: $\sin 2\phi_1 = 0.67 \pm 0.03$
Indirect: $\sin 2\phi_1 = 0.76 \pm 0.04$
Difference: $= 0.09 \pm 0.05$
Not statistically significant, but…

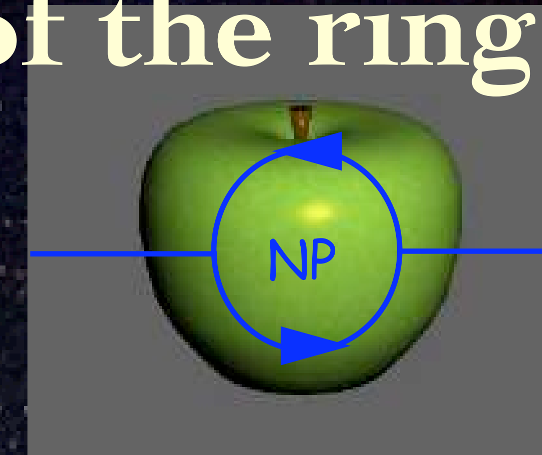
Model independent NP in B mixing
Add new amplitude to SM



$$A_d = A_d^{\rm SM}\left(1 + \left|A_d^{\rm NP}/A_d^{\rm SM}\right| e^{i2\phi_d^{\rm NP}}\right)$$

$\rightarrow$ modifies ϕ_1 to $\phi_1 + \phi_d^{NP}$

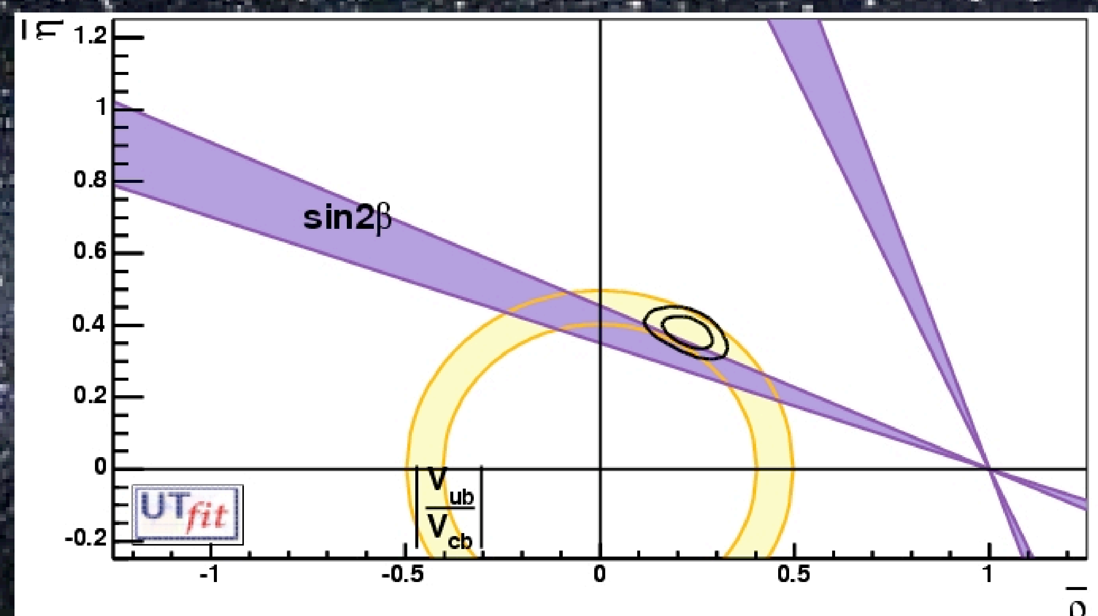
Fellowship of the ring



CLEO

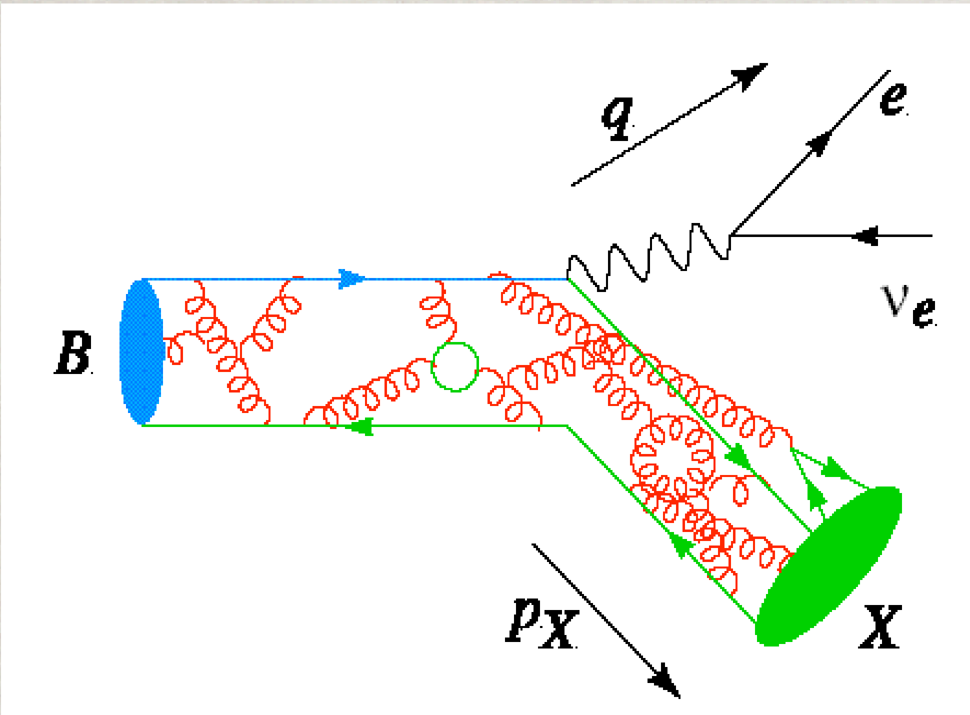
ARGUS

and many theorists



LEP x 4

Semileptonic B for V_{ub}



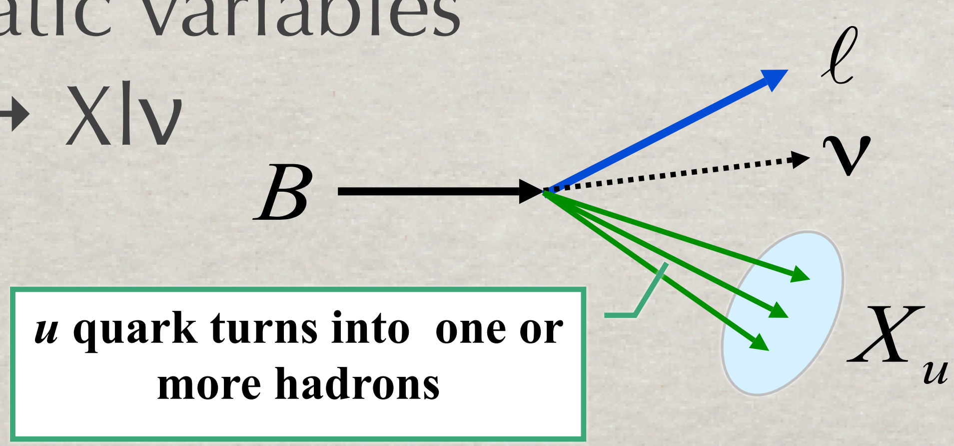
* $|V_{ub}|$ from tree level processes.

* Presence of a single hadronic current allows control of theoretical uncertainties.

$$|V_{cb}| \gg |V_{ub}|$$

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

kinematic variables for B → Xlν



$E_\ell =$ lepton energy

$q^2 = (p_\ell + p_\nu)^2$

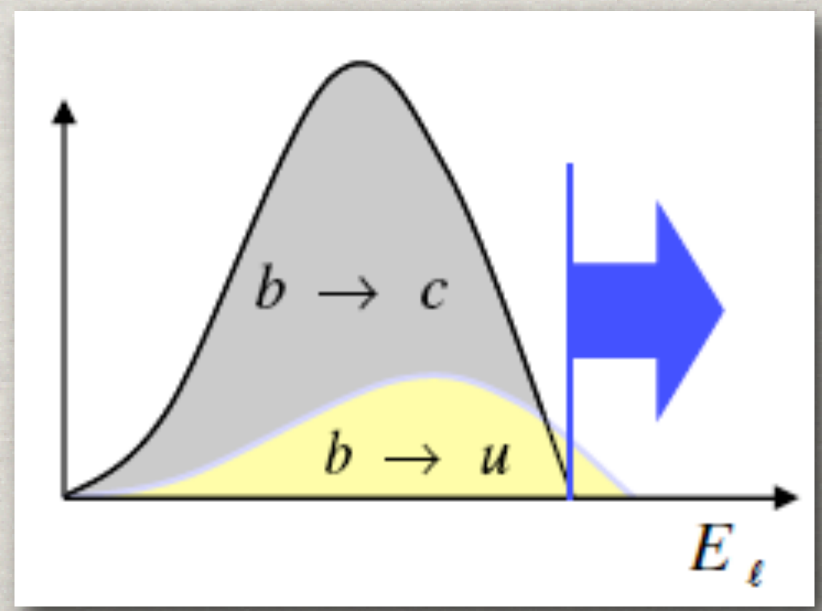
$m_X =$ mass of the hadronic part

The “Two Towers”

- Exclusive
  - good suppression of b --> c; high S/N
  - but, small BF
  - need Form Factor as a ftn. of q^2

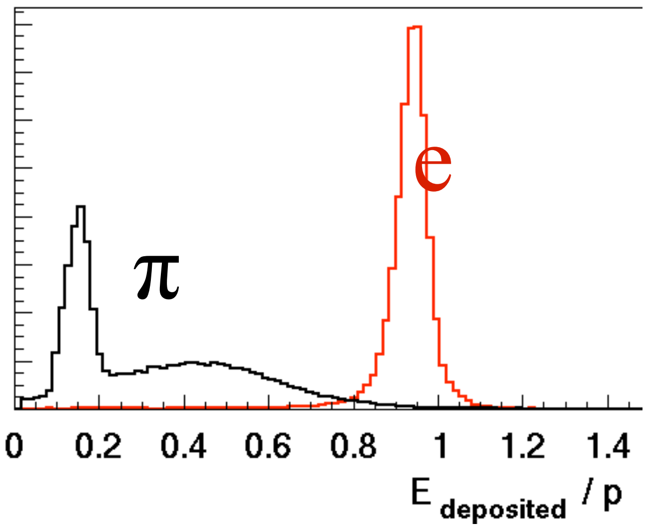
$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = |V_{ub}|^2 \frac{G_F^2}{24\pi^3} |\mathbf{p}_\pi|^3 \left|f^+(q^2)\right|^2$$

- Inclusive
  - easy at the parton-level
  - kinematic cuts to cope with b --> c
  - need to know non-pert. effects (SF)

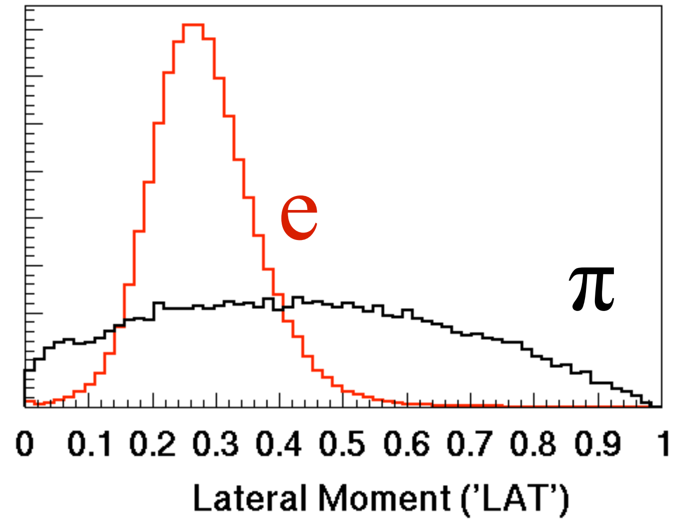


Electron and Muon identification in Belle

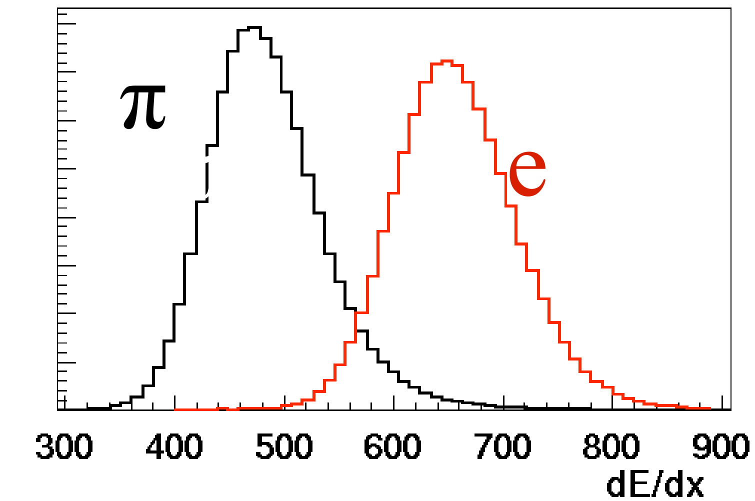
E/p from E.M.Calorimeter



Shower Shape



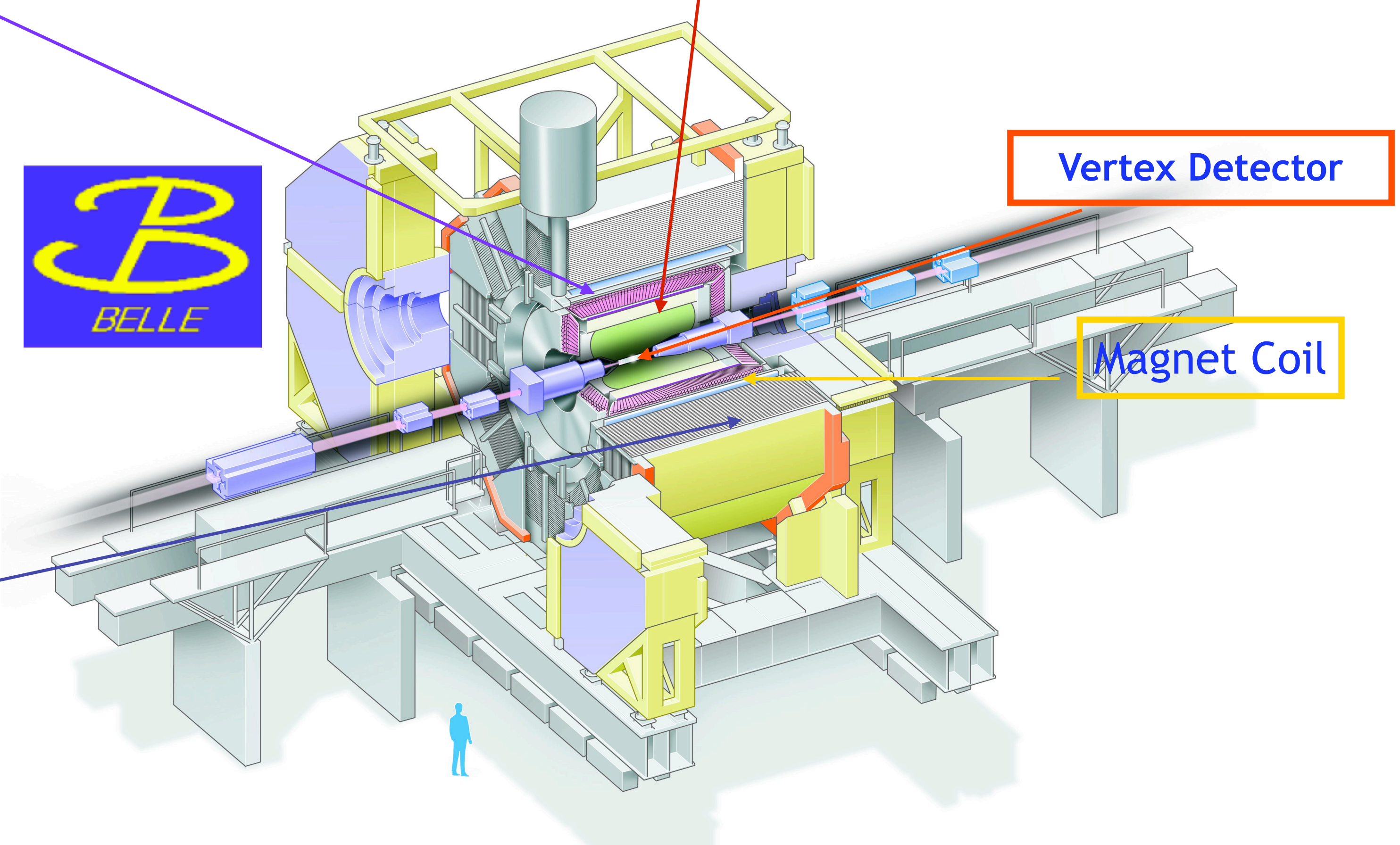
dE/dx from Driftchamber



Light yield in *Cerenkov Detector*

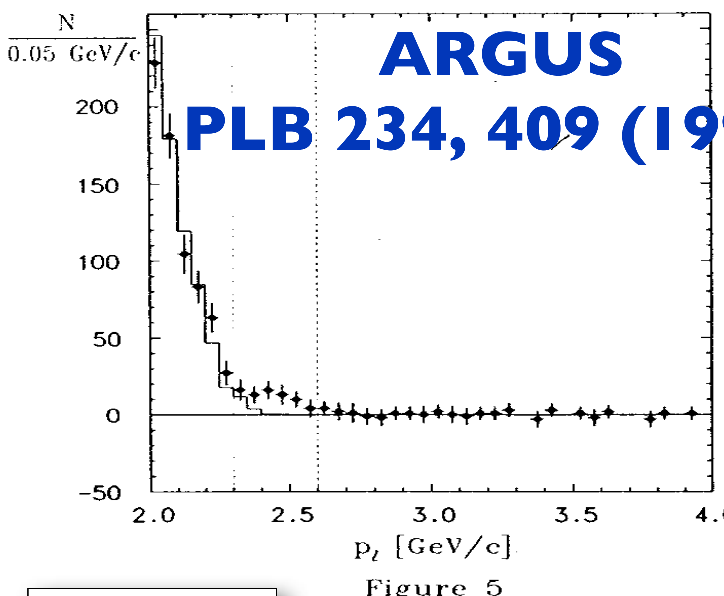
Track and cluster matching

Range and transverse scattering in Muon/ hadron detector

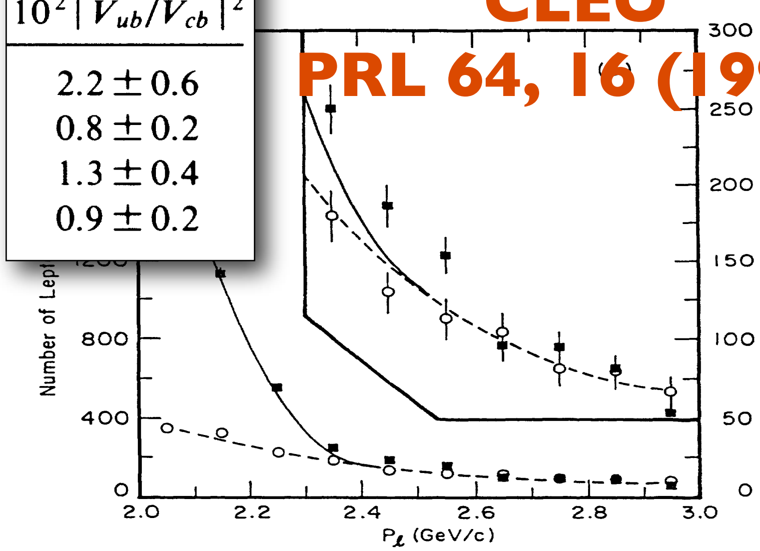


Notable Milestones

- non-zero V_{ub} from both inclusive & exclusive



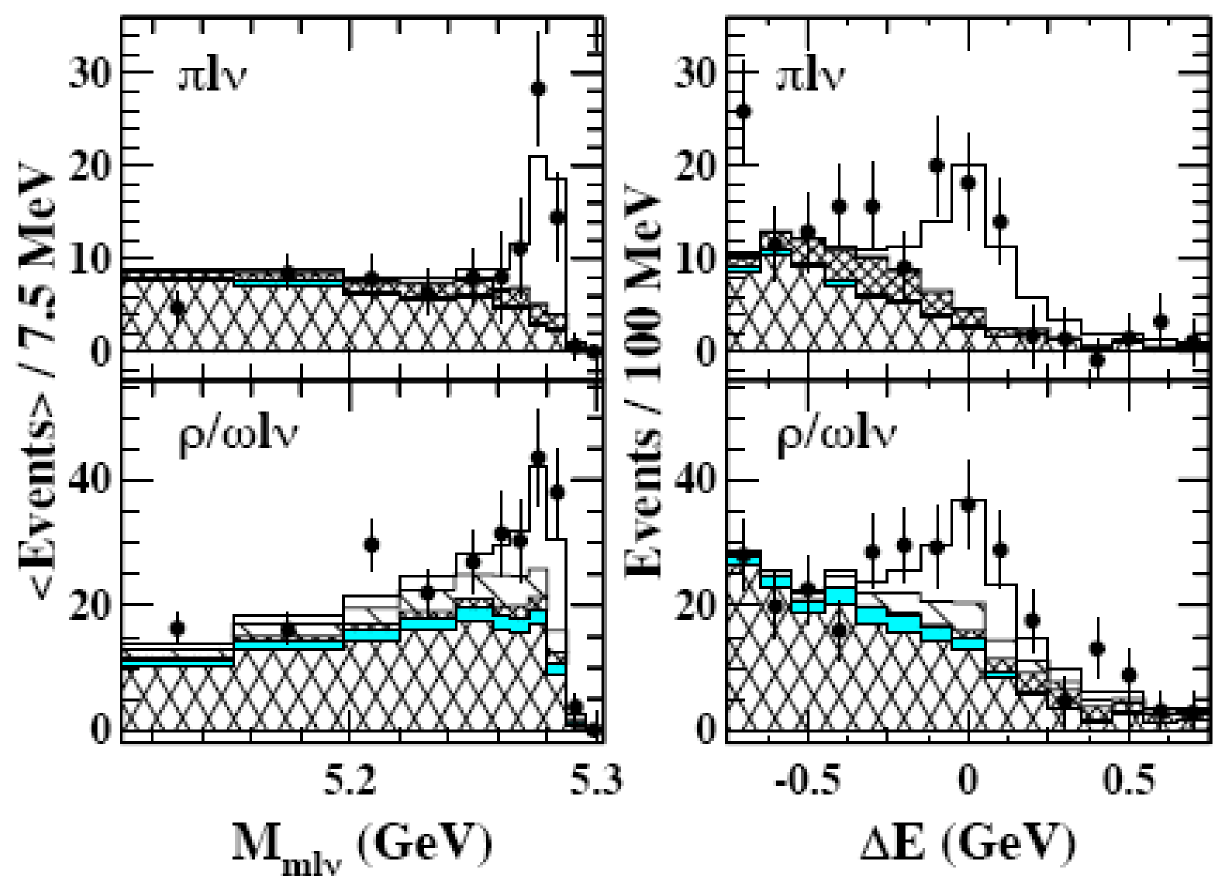
ARGUS
PLB 234, 409 (1990)



Average $10^2 \lvert V_{ub}/V_{cb} \rvert^2$
2.2 ± 0.6
0.8 ± 0.2
1.3 ± 0.4
0.9 ± 0.2

CLEO
PRL 64, 16 (1990)

CLEO, PRL 77, 5000 (1996)

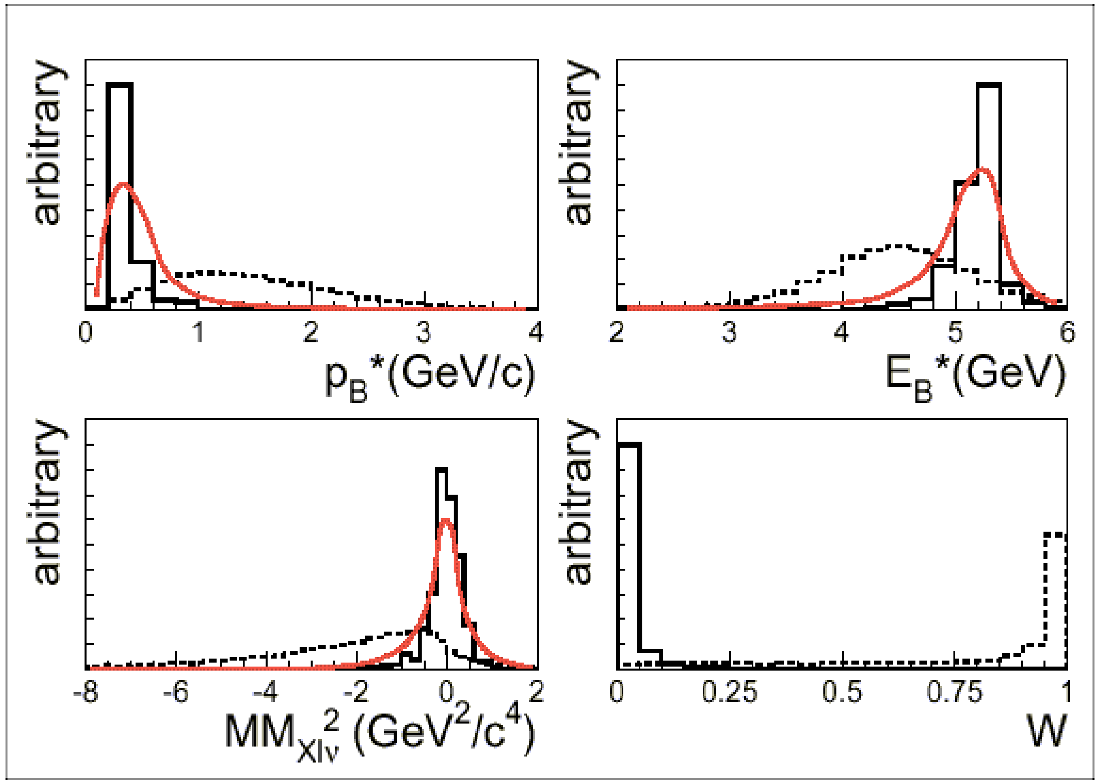


systematics. Averaging over the the different models, we find $|V_{ub}| = (3.3 \pm 0.2^{+0.3}_{-0.4} \pm 0.7) \times 10^{-3}$, where the errors are statistical, systematic (including B^0 lifetime), and estimated model dependence. This agrees with the

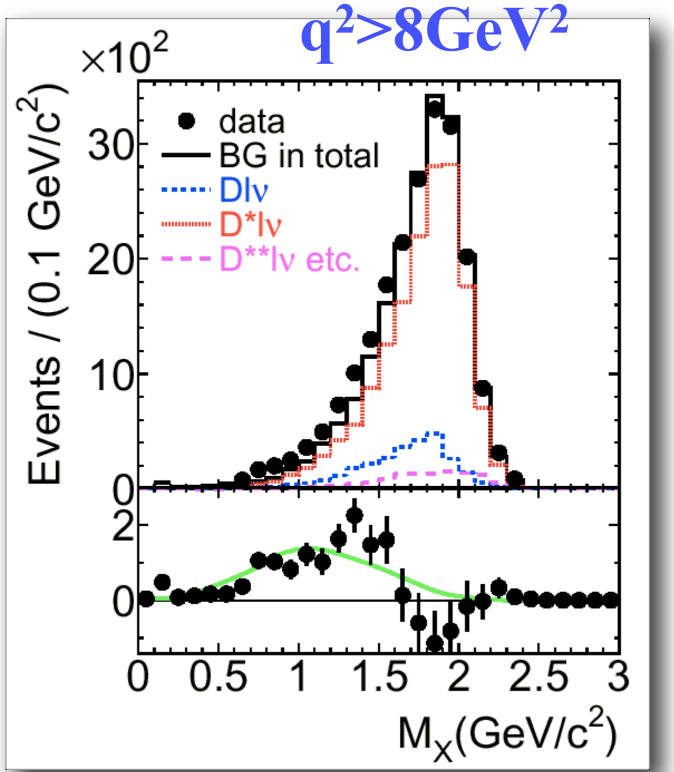
Novel X_u recon. by Belle

- ν reconstruction by $(E,p)_{miss}$
- "**simulated annealing**" to separate the particles as belonging to signal *B* and the other *B*

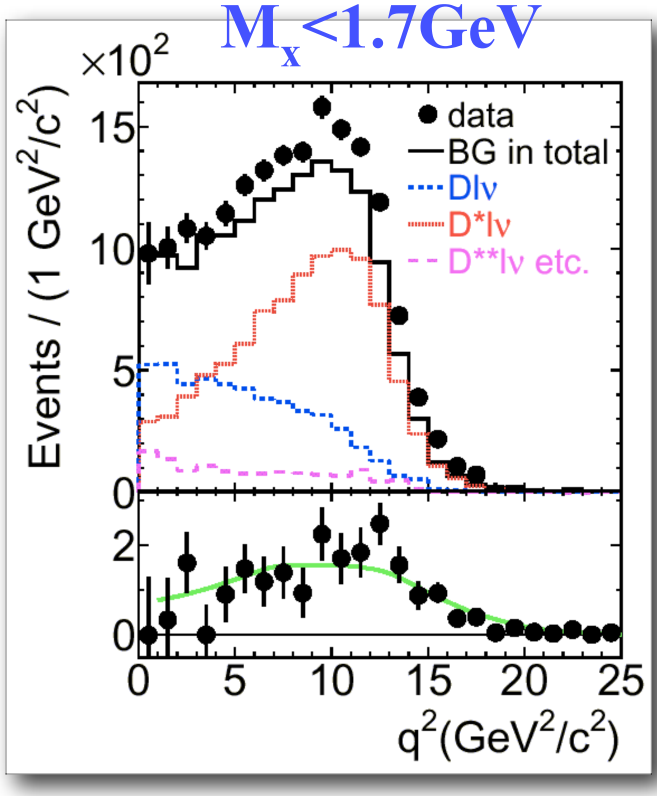
  see S. Kirkpatrick et al., **Science** 220, No.4598 (1983)
- good effi. w/ reasonable M_x resol.
- Belle's result: **PRL 92, 101801(2004)**
- **First result with M_x & q^2 cut**



q^2>8GeV^2



M_x<1.7GeV



In the PDG(2004) mini-review on V_{ub}

uncertainties $\pm 0.0044 \pm 0.0048\,^{+[illegible]}_{-0.0012}$, where the first error is statistical, the second is systematic, and the third is the uncertainty due to the form factor model variations. We combine the last two in quadrature.

DETERMINATION OF V_{ub}

Updated December 2003 by M. Battaglia (University of California, Berkeley and LBNL) and L. Gibbons (Cornell University, Ithaca) .

The precise determination of
a robust, well-understood uncertai
goals of the heavy flavor physics pro
and theoretically. Because $|V_{ub}|$, t
CKM mixing matrix, provides a bo
one of the triangles representing th
CKM matrix, it plays a crucial rol

a preference of experimental technique. Indeed, we look forward to a similar (or improved) analysis when a sample of clean results based on fully tagged B samples have been obtained for all regions of phase space.

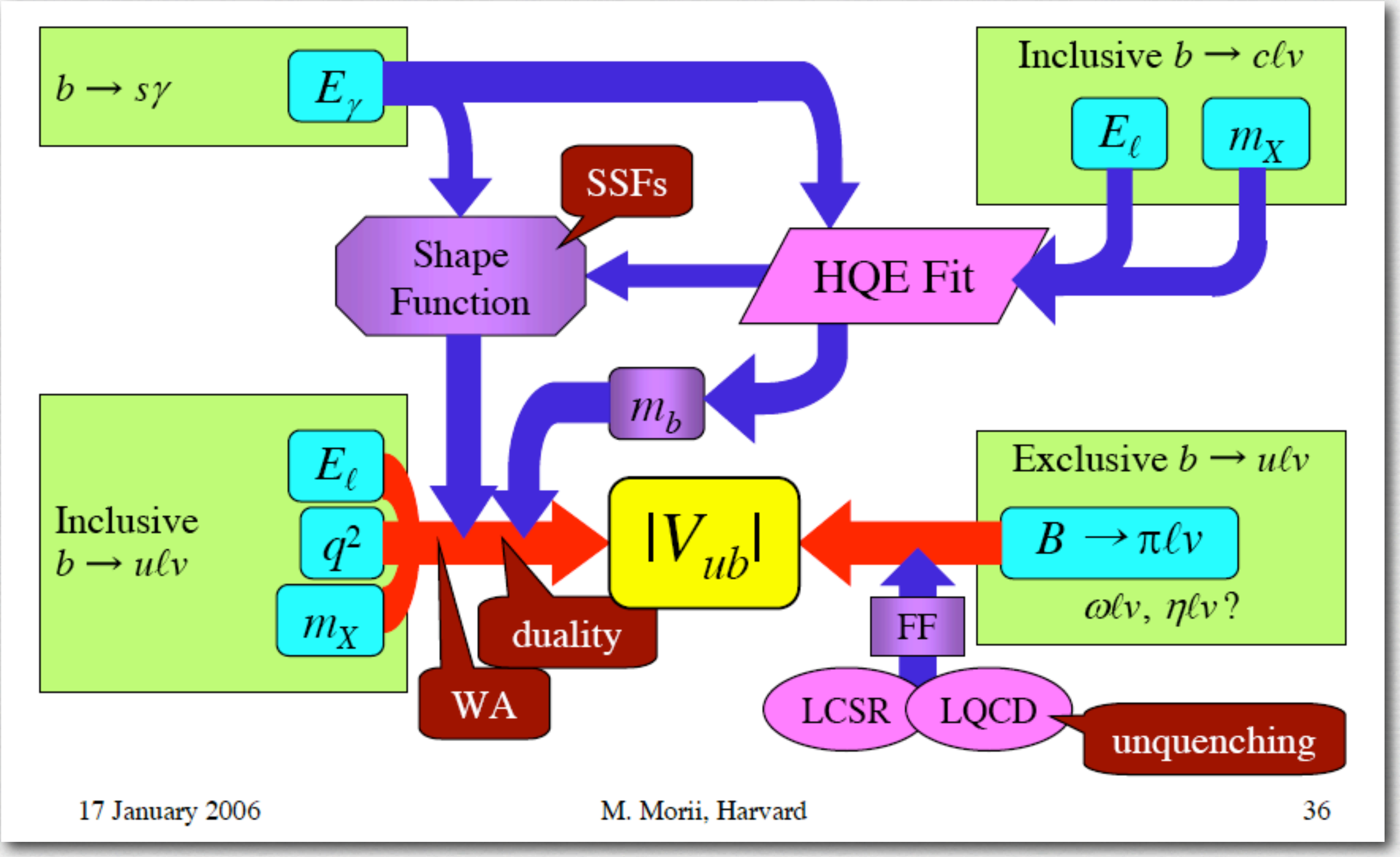
At present only Belle [46] has contributed a result for this region of phase space, so for now we take this result as the "central value":

$$|V_{ub}|/10^{-3} = 4.63 \pm 0.28_{\rm stat} \pm 0.39_{\rm sys} \pm 0.48_{\rm f_{qM}} \pm 0.32_{\Gamma\rm thy} \pm \sigma_{\rm WA} \pm \sigma_{\rm SSF} \pm \sigma_{\rm LQD}\ . \quad (5)$$

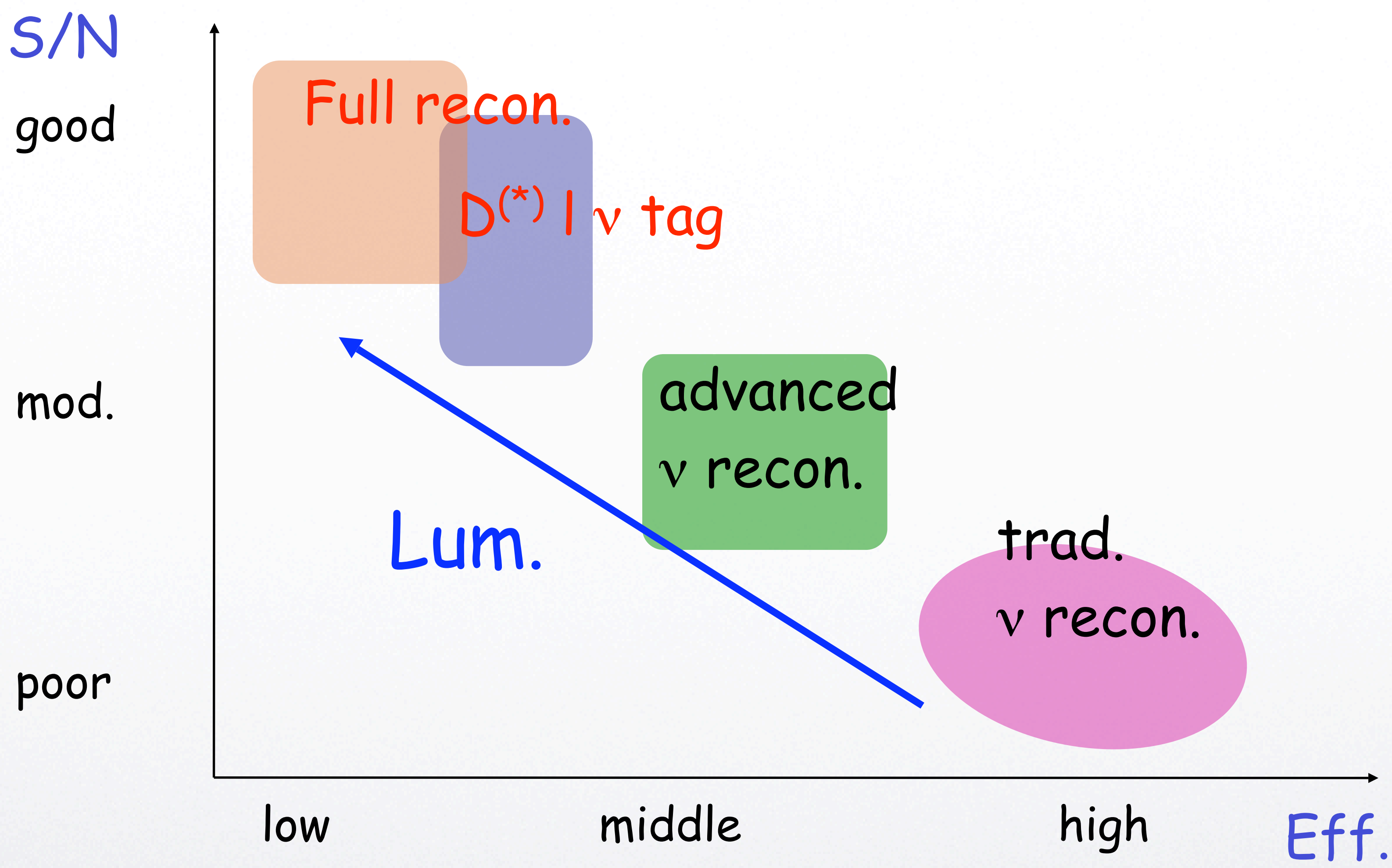
Additional measurements by the B factories of the rate in this region of phase space will soon improve the experimental uncertainties.

We must determine the last three uncertainties for weak

Roadmap for V_{ub} - *"Morri's chart"*



Exclusive $B \to X_u \ell \nu$



$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = |V_{ub}|^2 \frac{G_F^2}{24\pi^3} |\mathbf{p}_\pi|^3 \left| f^+(q^2) \right|^2$$

How well can we measure the q^2 dist. for $B \to X_u l \nu$?

Form-factors for exclusive
- for the non-pert. QCD effect

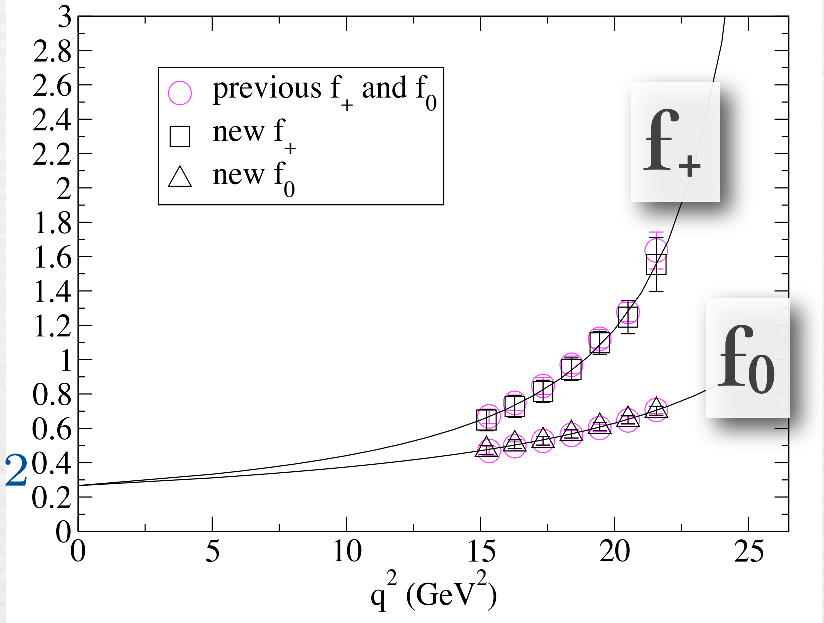
Hadronic current H^μ for $\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}$:

$$H^\mu = \langle \pi^+(p') | u \gamma^\mu b | \bar{B}^0(p) \rangle = f^+(q^2)(p+p')^\mu$$

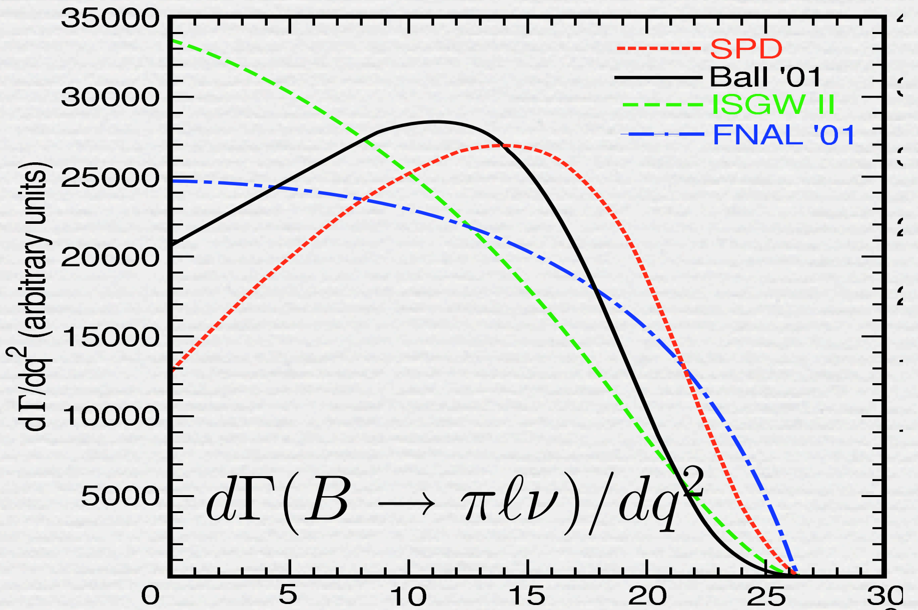
In the limit of massless lepton,

$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2 d\cos\theta_\ell} = |V_{ub}|^2 \frac{G_F^2}{32\pi^3} |\vec{p}_\pi|^3 \sin^2\theta_\ell \left| f^+(q^2) \right|^2$$

HPQCD, PRD73, 074502 (2006)



- Form-factor models based on
  - Relativistic quark models (ISGW2)
  - LCSR for low q2
  - LQCD for high q2



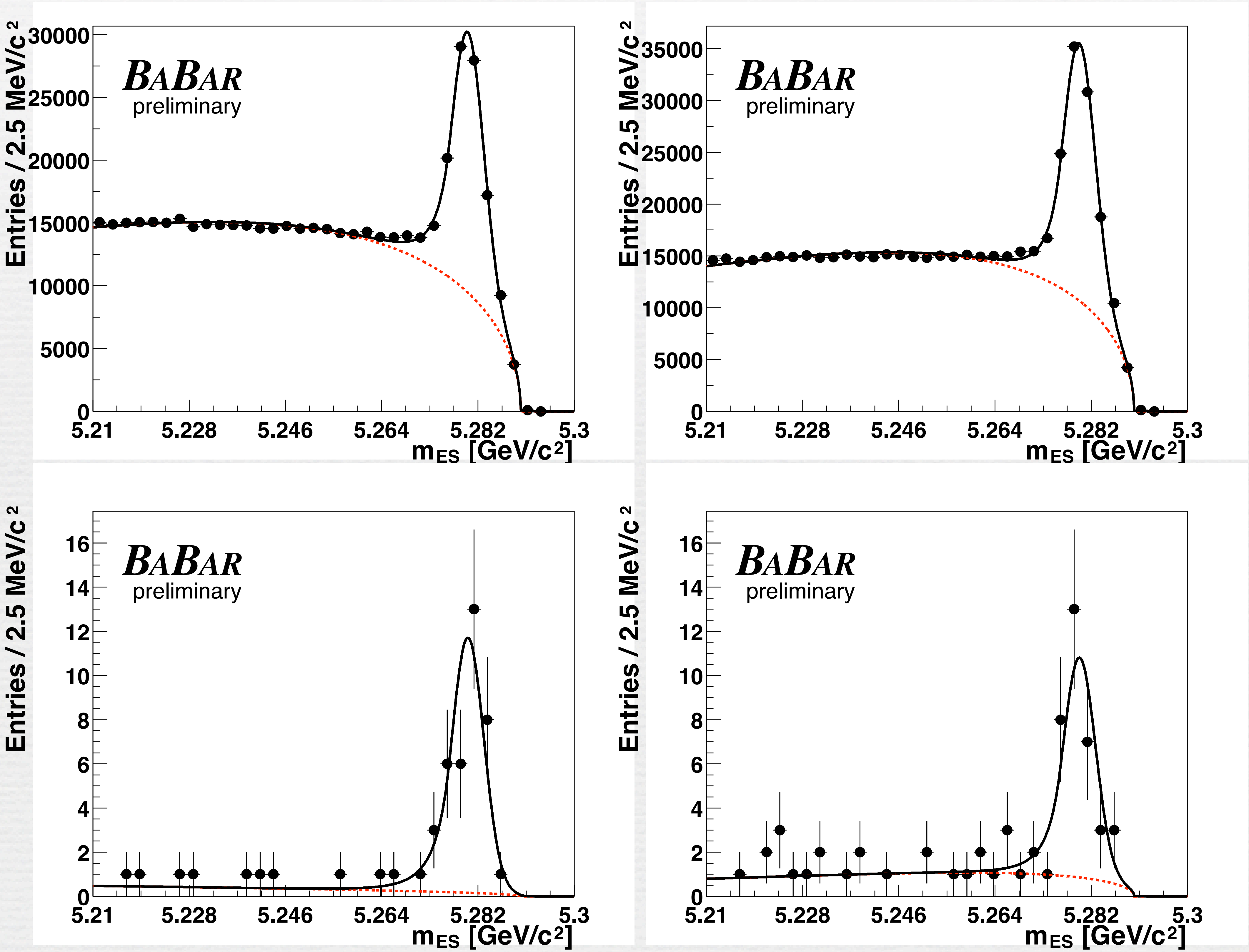
large variations among models

How well can we measure the q^2 dist. for $B \to X_u l \nu$?

To tag, or not to tag...

- tagged with
  - Hadronic B (“Full Reconstruction”)
  - Semileptonic B
- untagged
  - loose neutrino reconstruction

Tagging with hadronic B ("Full Recon")



Tagging with semileptonic B

$$B_{\rm tag} \to D^* \ell^+ \nu \; , \;\; B_{\rm sig} \to \pi/\rho \; \ell^+ \nu$$

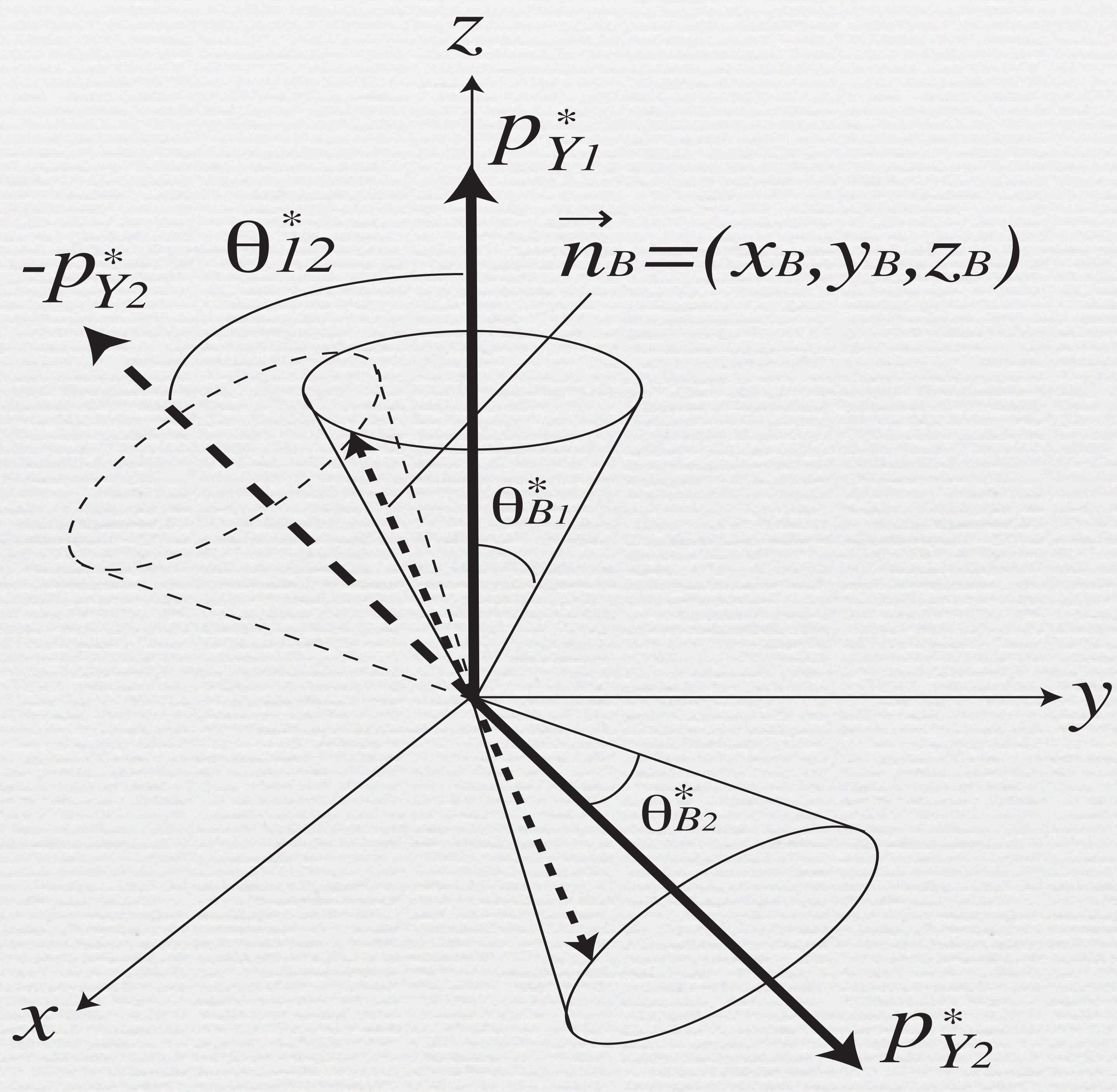


Fig. 1. Kinematics of the double semileptonic decay.

$B \to \pi\ell\nu$ with $D^*\ell\nu$ tagging

BELLE

$B_{\rm tag} \to D^*\ell^+\nu$, $B_{\rm sig} \to \pi/\rho\, \ell^+\nu$

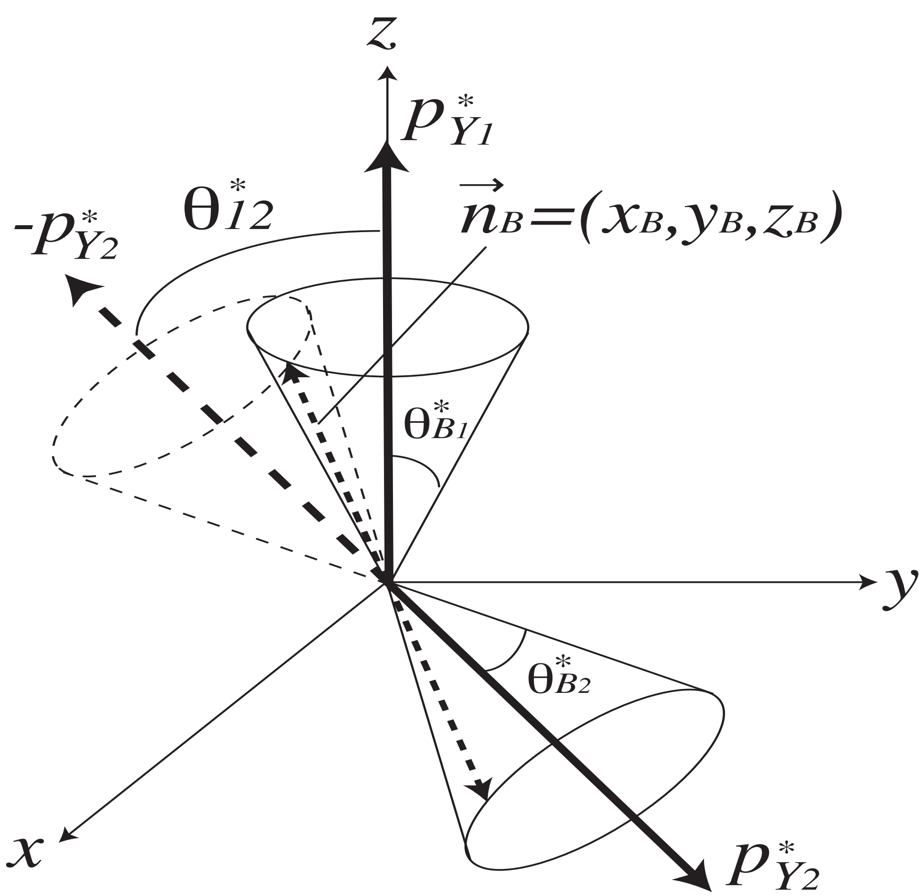
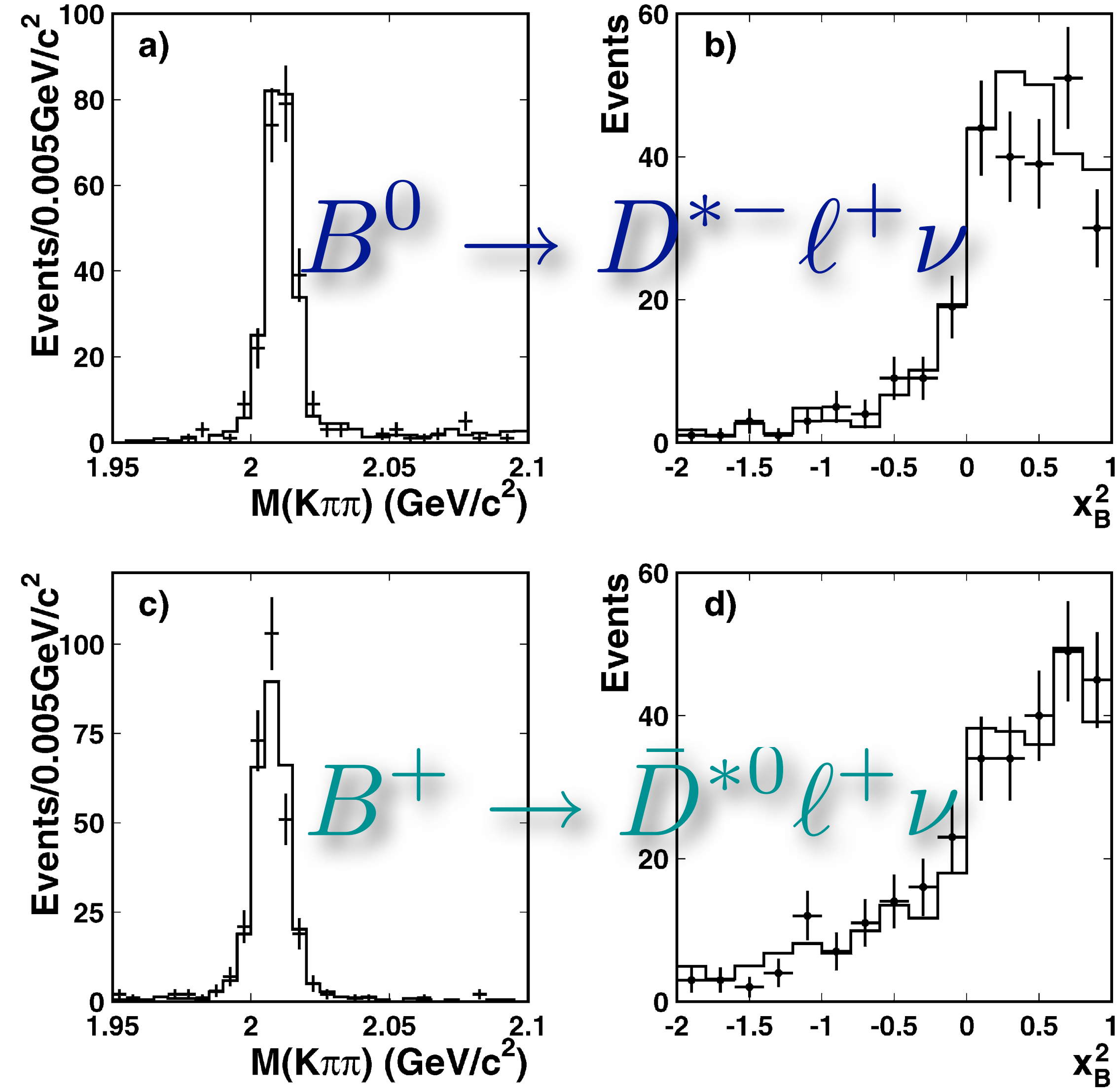


Fig. 1. Kinematics of the double semileptonic decay.

calibration modes



$$z_B = \cos\theta^*_{B_1},\ y_B = (\cos\theta^*_{B_2} - \cos\theta^*_{B_2}\cos\theta^*_{12})/\sin\theta^*_{12},$$

$$x_B{}^2 = 1 - \frac{1}{\sin^2\theta^*_{12}}(\cos^2\theta^*_{B_1} + \cos^2\theta^*_{B_2} - 2\cos\theta^*_{B_1}\cos\theta^*_{B_2}\cos\theta^*_{12})$$

for true signal, $0 < x_B^2 < 1$

$\exists$ 2-fold ambiguity for $\vec{n}_B$

$B \to \pi\ell\nu$ with $D^*\ell\nu$ tagging

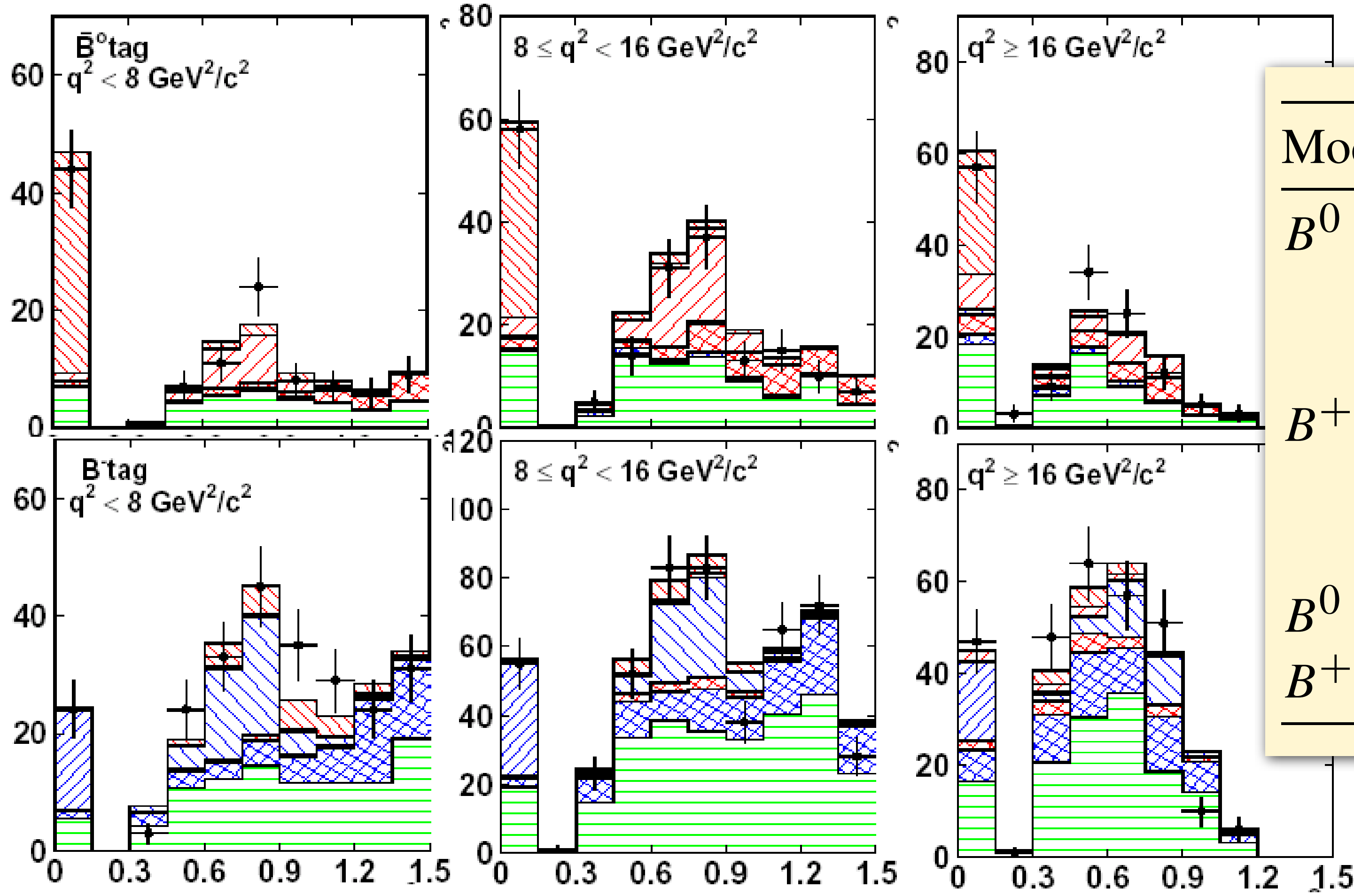
- Because of the 2-fold ambig. in the B direction, q^2 is not exactly measured
- Use modified q^2 $q^2 \Leftarrow (E_{\rm beam} - E_{X_u})^2 - |\vec{p}_{X_u}|^2$

$\sigma_{q^2} : 0.95 \sim 0.32\ \mathrm{GeV}^2$

Detection efficiency matrix based on the LCSR model in units of 10^{-3}

Generated mode	True q^2 (GeV^2/c^2)	Reconstructed q^2 (GeV^2/c^2)		
		< 8	8–16	$\geqslant 16$
$\pi^-\ell^+\nu$	< 8	1.71	0.05	0.00
	8–16	0.21	1.82	0.03
	$\geqslant 16$	0.00	0.24	1.89
$\rho^0\ell^+\nu$	< 8	1.50	0.10	0.01
	8–16	0.08	1.71	0.08
	$\geqslant 16$	0.01	0.13	1.82

$B \to \pi \ell \nu$ with $D^* \ell \nu$ tagging

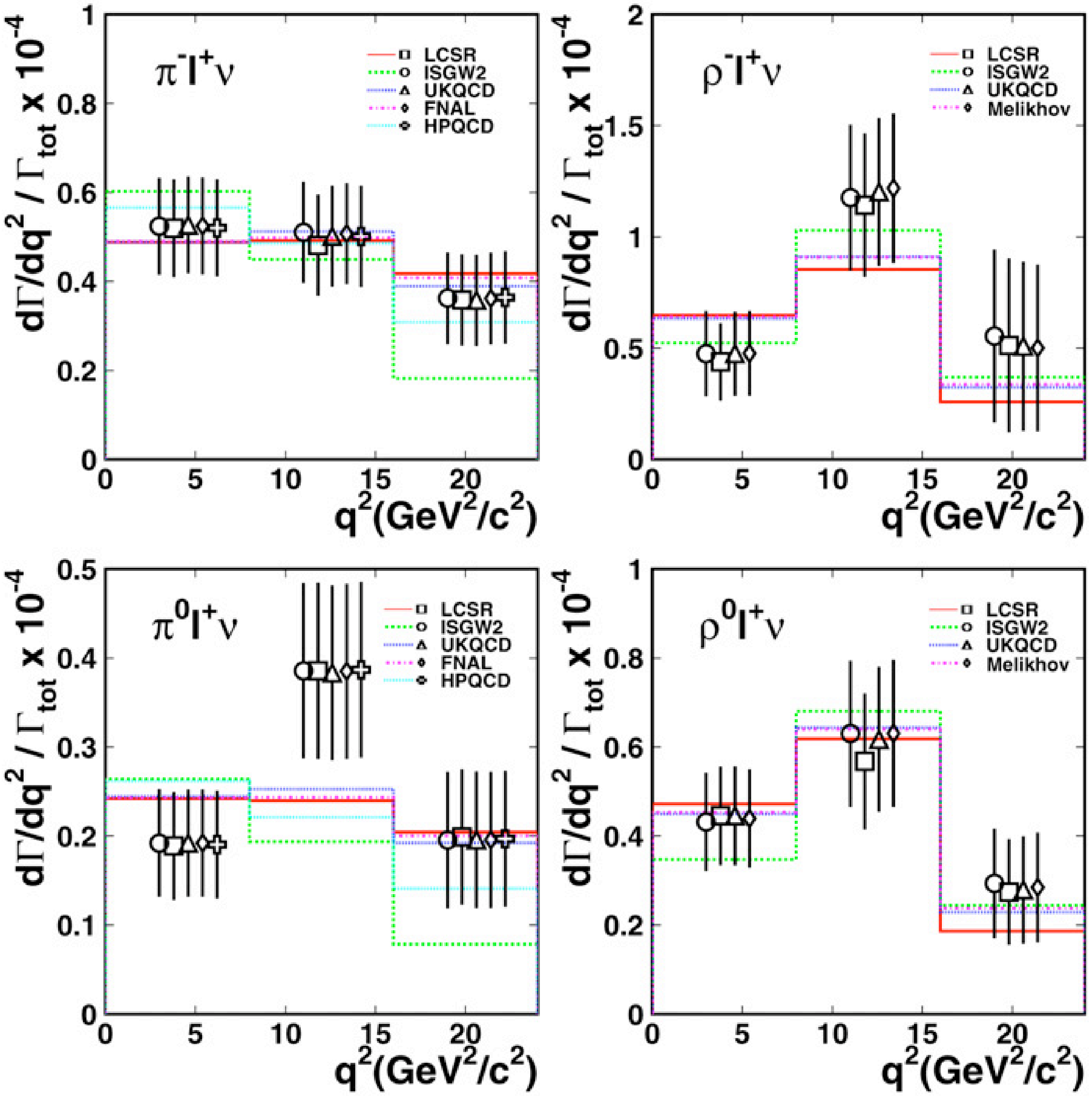


Modes	q^2 reg	Branching fraction ($\times 10^{-4}$)
$B^0 \to \pi^- \ell^+ \nu$	Total	$1.38 \pm 0.19 \pm 0.14 \pm 0.03$
	> 16	$0.36 \pm 0.10 \pm 0.04 \pm 0.01$
	< 16	$1.02 \pm 0.16 \pm 0.11 \pm 0.03$
$B^+ \to \pi^0 \ell^+ \nu$	Total	$0.77 \pm 0.14 \pm 0.08 \pm 0.00$
	> 16	$0.20 \pm 0.08 \pm 0.02 \pm 0.00$
	< 16	$0.57 \pm 0.12 \pm 0.06 \pm 0.00$
$B^0 \to \rho^- \ell^+ \nu$	Total	$2.17 \pm 0.54 \pm 0.31 \pm 0.08$
$B^+ \to \rho^0 \ell^+ \nu$	Total	$1.33 \pm 0.23 \pm 0.17 \pm 0.05$

Signal yields and the χ^2 values for each q^2 region

Mode	$N_{<8}$	N_{8-16}	$N_{\geqslant 16}$
$\pi^- l^+ \nu$	64.8 ± 11.9	63.2 ± 12.4	40.6 ± 11.3
$\rho^- l^+ \nu$	22.1 ± 8.0	53.2 ± 13.5	30.9 ± 16.0
$\pi^0 l^+ \nu$	18.1 ± 5.1	34.5 ± 8.3	18.6 ± 6.5
$\rho^0 l^+ \nu$	47.2 ± 11.2	68.3 ± 16.5	32.5 ± 12.3
χ^2/ndf	172.4/(200−4)	190.7/(200−4)	172.1/(200−4)

$B \to \pi\ell\nu$ with $D^*\ell\nu$ tagging



PLB 648, 139 (2007)

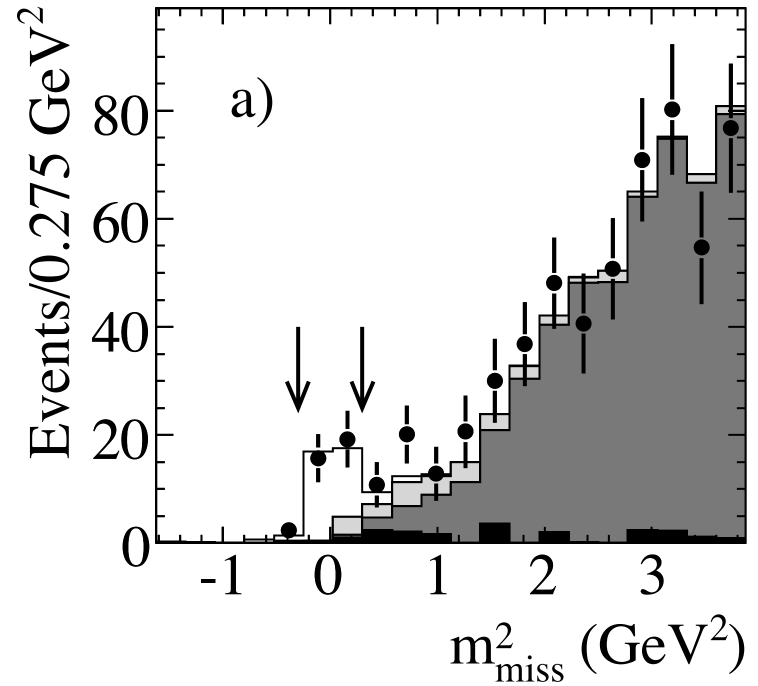
Mode	$\lvert V_{ub}\rvert(\times 10^{-3})$
$\pi^-\ell^+\nu$	$3.59 \pm 0.51 \pm 0.20^{+0.62}_{-0.41}$
$\pi^0\ell^+\nu$	$3.63 \pm 0.70 \pm 0.20^{+0.63}_{-0.41}$
$\pi^-\ell^+\nu + \pi^0\ell^+\nu$	$3.60 \pm 0.41 \pm 0.20^{+0.62}_{-0.41}$
$\pi^-\ell^+\nu$	$4.02 \pm 0.57 \pm 0.22^{+0.59}_{-0.41}$
$\pi^0\ell^+\nu$	$4.06 \pm 0.78 \pm 0.22^{+0.60}_{-0.41}$
$\pi^-\ell^+\nu + \pi^0\ell^+\nu$	$4.03 \pm 0.46 \pm 0.22^{+0.59}_{-0.41}$

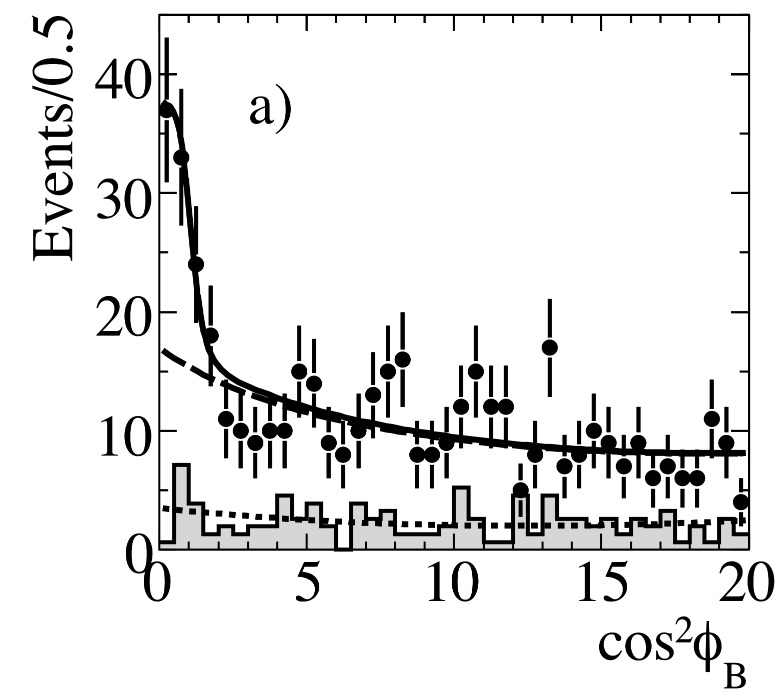
FNAL

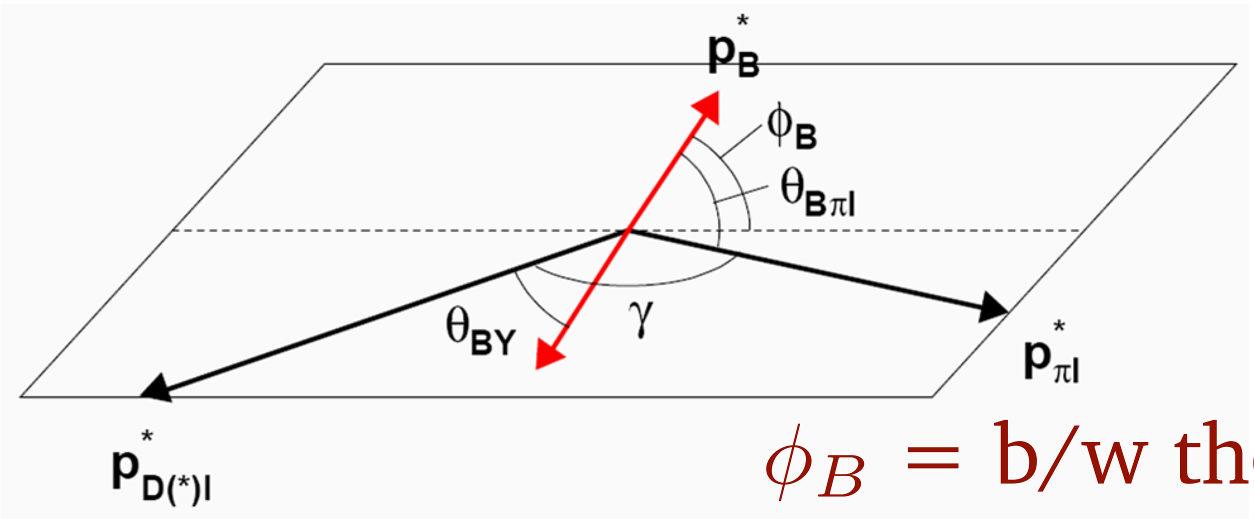
HPQCD

$B \to \pi\ell\nu$ with $B_{\rm tag}$

- Hadronic tag
  - charge/flavor correl. for π & ℓ
  - no (small) add'l neutral energy
  - $|m^2_{\rm miss}| < 0.3$ GeV^2
- Semileptonic tag
  - $D^{(*)}\ell\nu$ for $B_{\rm tag}$
  - no (small) add'l neutral energy
  - max-like. fit to $\cos^2\phi_B$



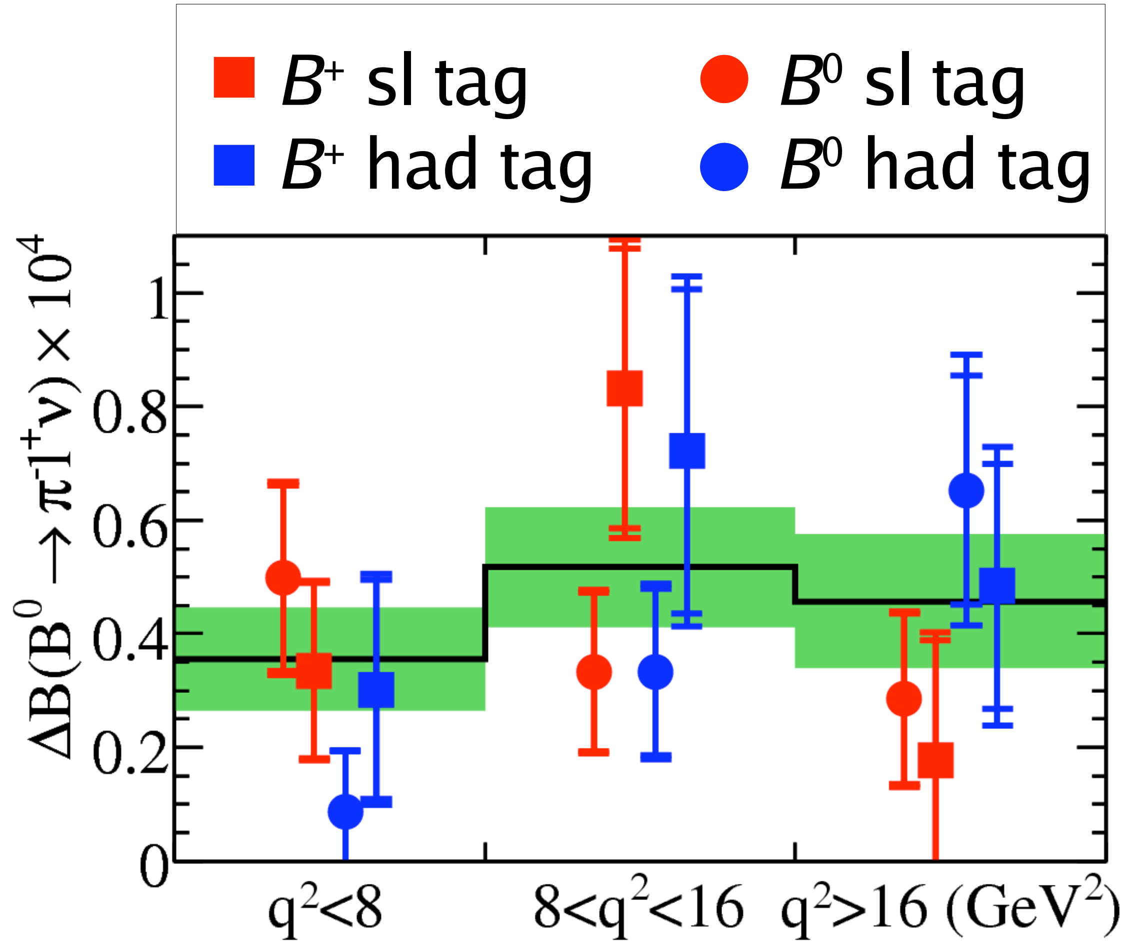




ϕ_B = b/w the B and the plane of $(D^{(*)}\ell,\pi\ell)$

$B \to \pi \ell \nu$ with B_{tag}

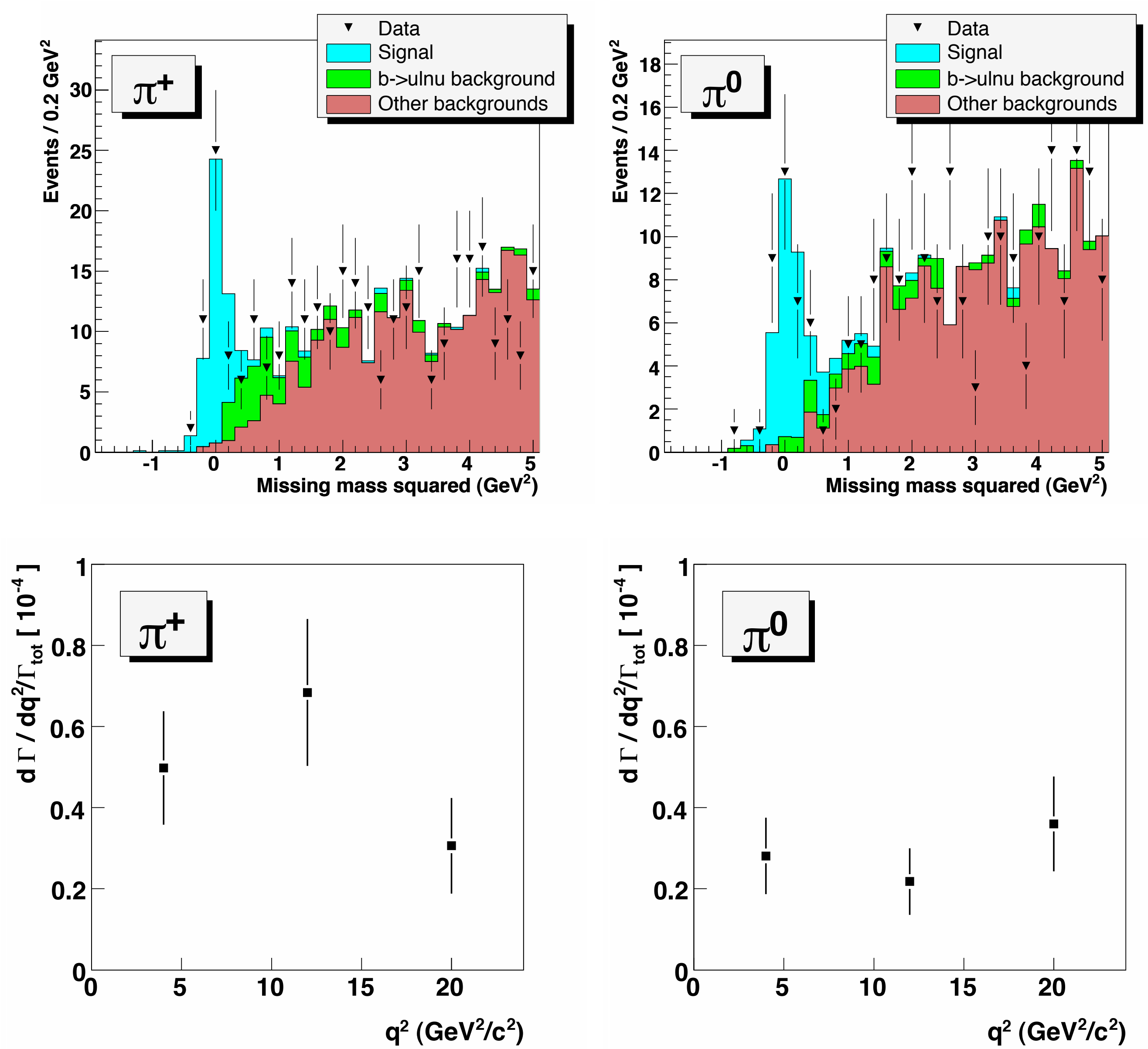
PRL 97, 211801 (2006)



	q^2 (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
Ball-Zwicky [5]	<16	5.44 ± 1.43	$3.2 \pm 0.2 \pm 0.1^{+0.5}_{-0.4}$
Gulez *et al.* [6]	>16	1.46 ± 0.35	$4.5 \pm 0.5 \pm 0.3^{+0.7}_{-0.5}$
Okamoto *et al.* [7]	>16	1.83 ± 0.50	$4.0 \pm 0.5 \pm 0.3^{+0.7}_{-0.5}$
Abada *et al.* [8]	>16	1.80 ± 0.86	$4.1 \pm 0.5 \pm 0.3^{+1.6}_{-0.7}$

HPQCD → (Gulez *et al.*)

$B \to \pi \ell \nu$ with full-recon. $B_{\rm tag}$



preliminary (hep-ex/0610054)

$\mathcal{B}(B \to \pi^+ \ell \nu) =$
$(1.49 \pm 0.26_{\rm stat} \pm 0.06_{\rm syst}) \times 10^{-4}$

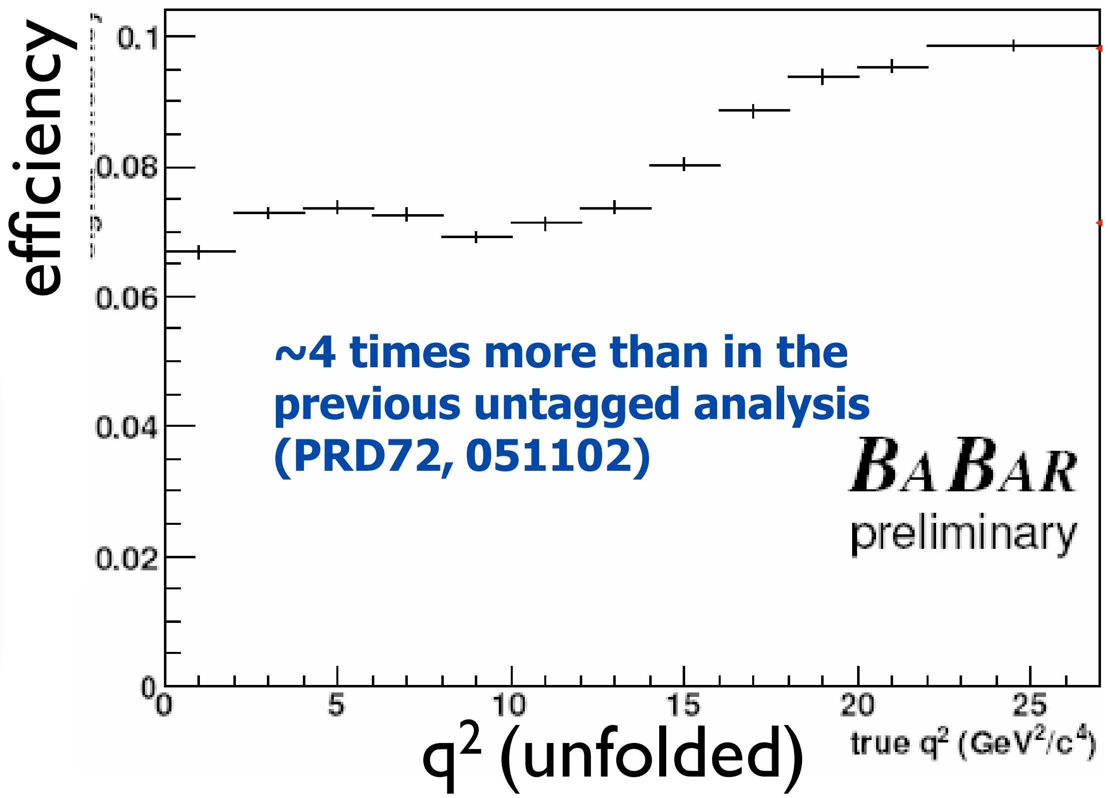
$\mathcal{B}(B \to \pi^0 \ell \nu) =$
$(0.86 \pm 0.17_{\rm stat} \pm 0.06_{\rm syst}) \times 10^{-4}$

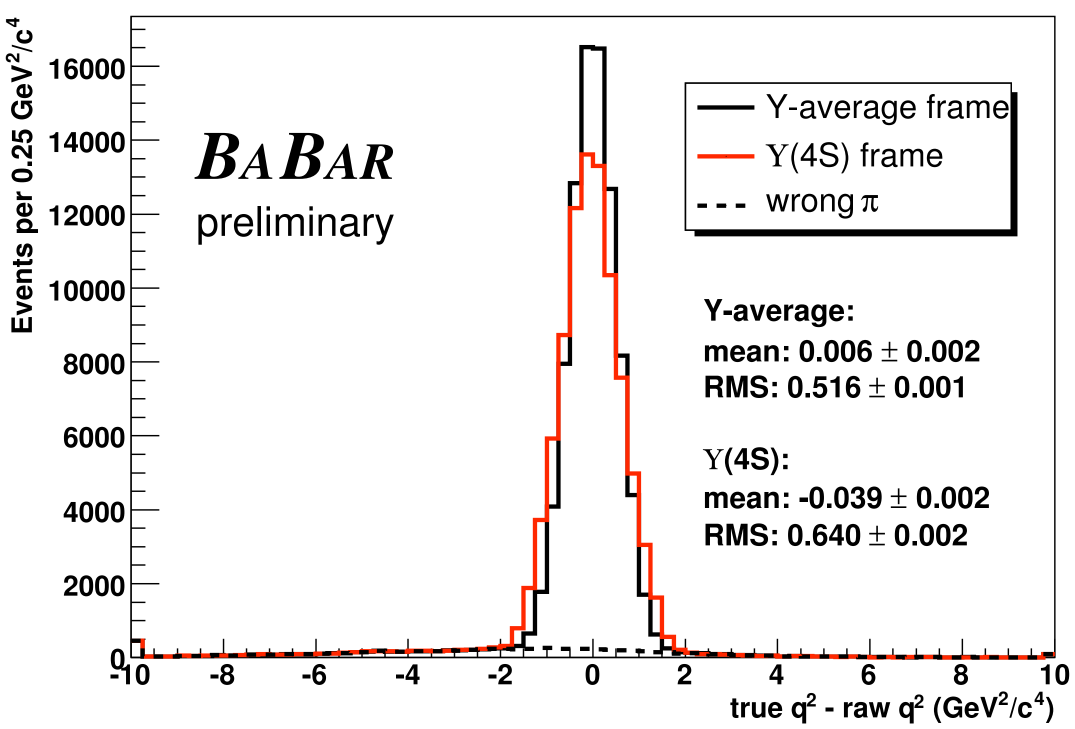
$N_{BB} = 535 \times 10^6$

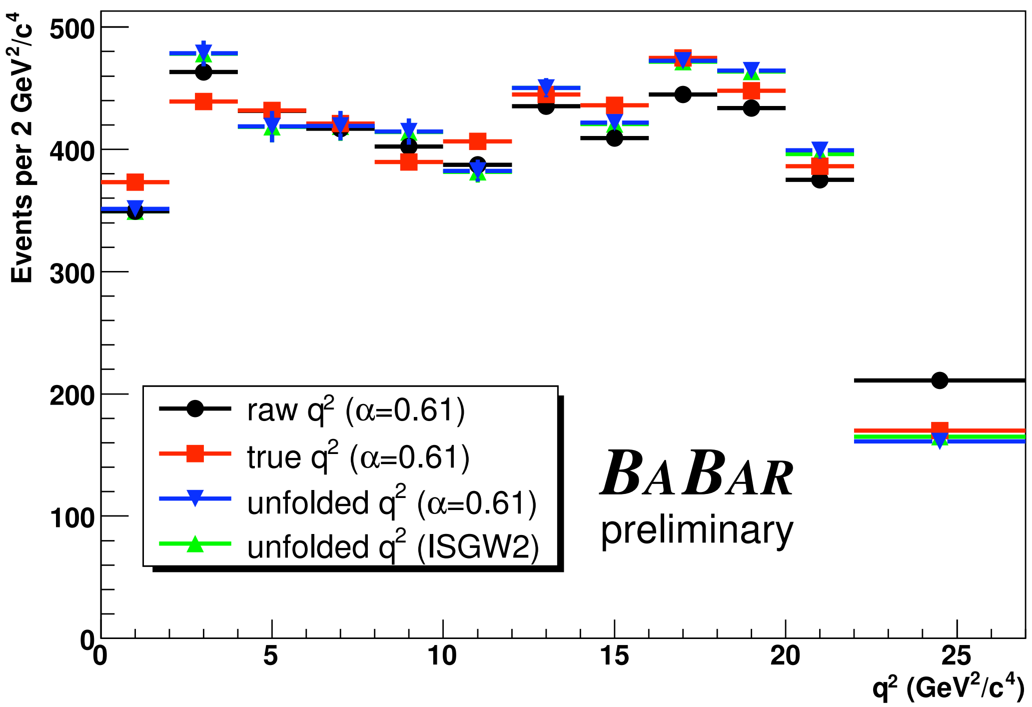
Measurement of the $B^0 \to \pi^- \ell^+ \nu$ Form-Factor Shape and Branching Fraction, and Determination of $|V_{ub}|$ with a Loose Neutrino Reconstruction Technique

- loose requirement on $\pi^- \ell^+$
- cuts optimized as a ftn. of q^2
- eff. up by ~4 times
- "Y-averaged" q^2

$$\tilde{q}^2 = \frac{1}{4}\sum_{i=1}^{4} q_i^2$$







Measurement of the $B^0 \to \pi^- \ell^+ \nu$ Form-Factor Shape and Branching Fraction, and Determination of $|V_{ub}|$ with a Loose Neutrino Reconstruction Technique

binned max. lik'd fit to (m_{ES}, ΔE, q^2)

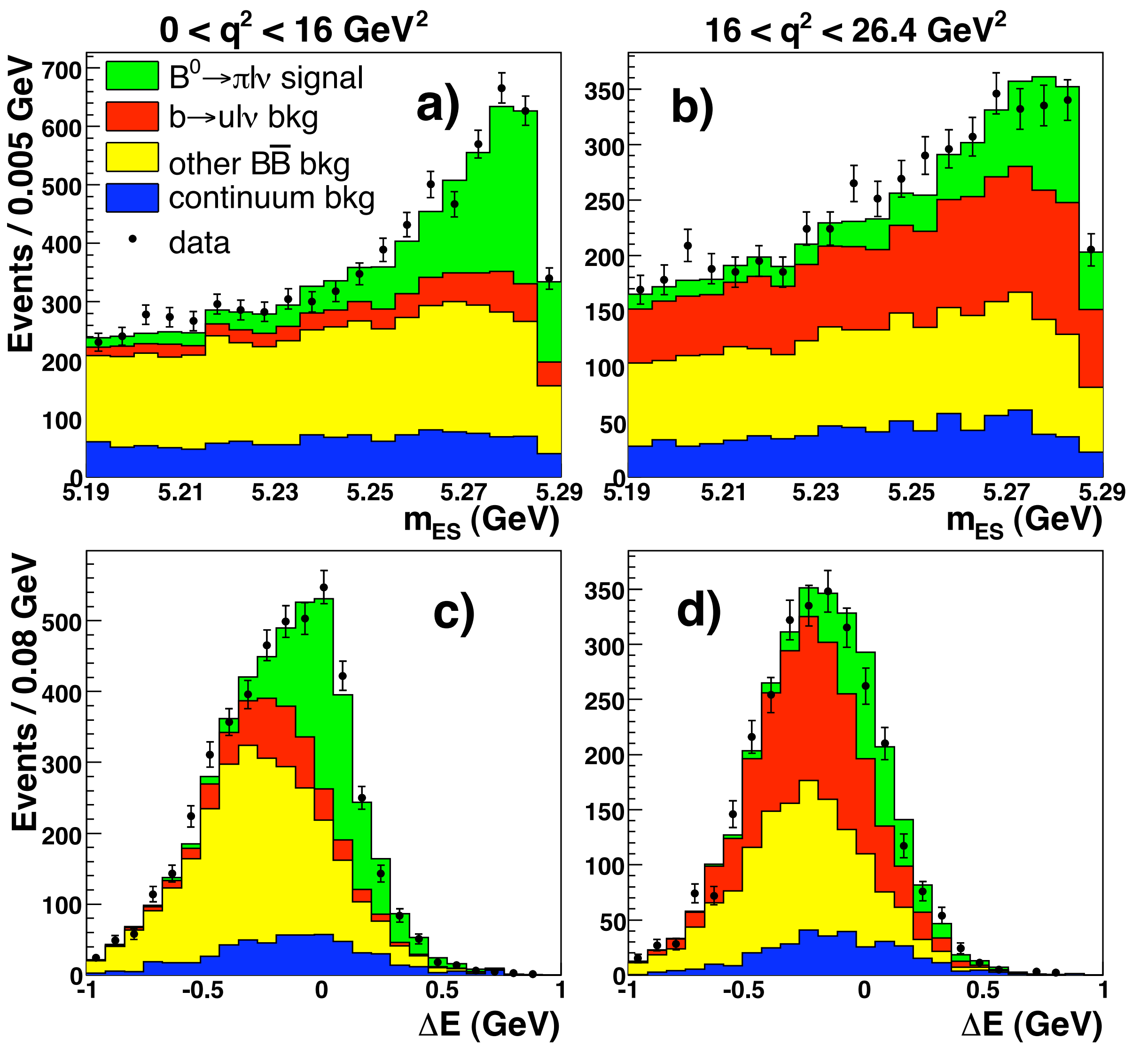
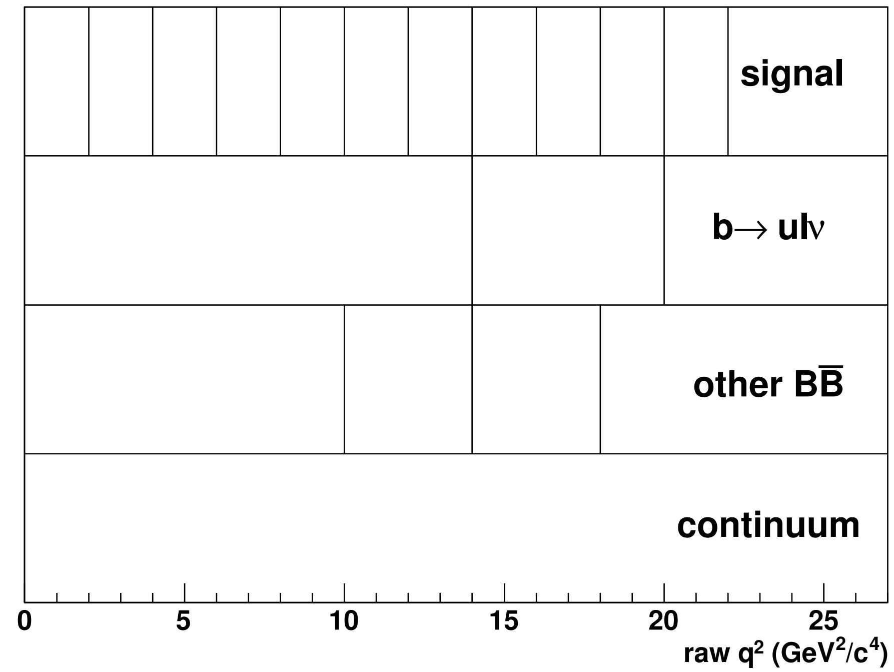
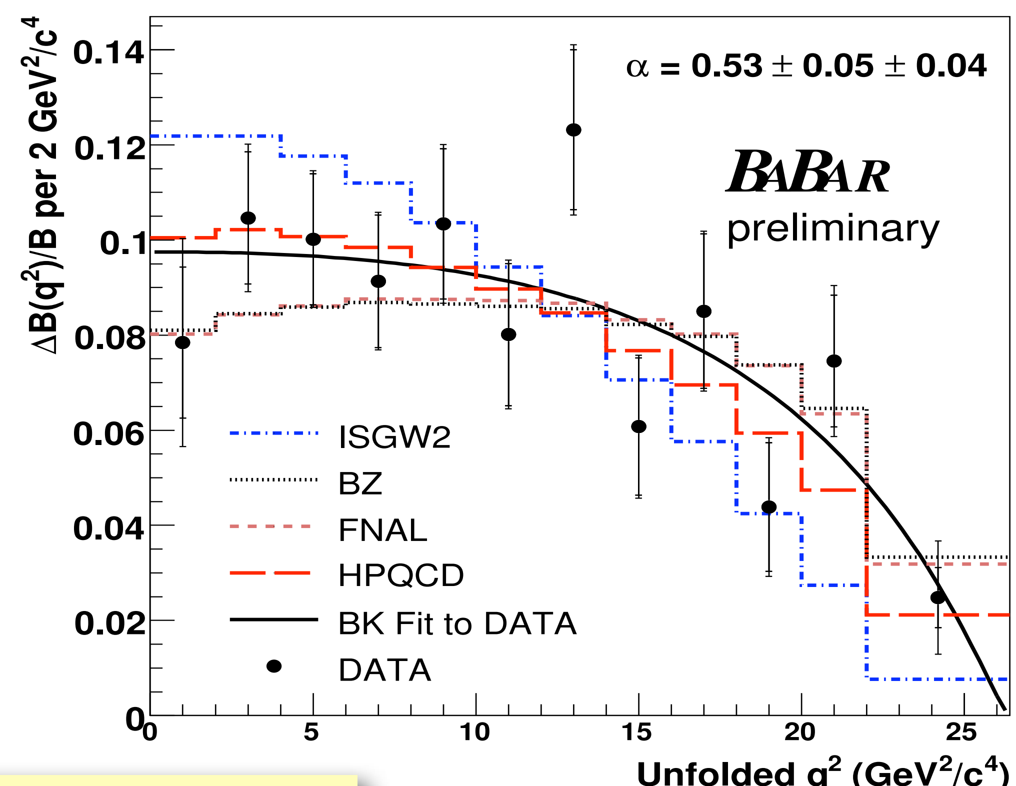


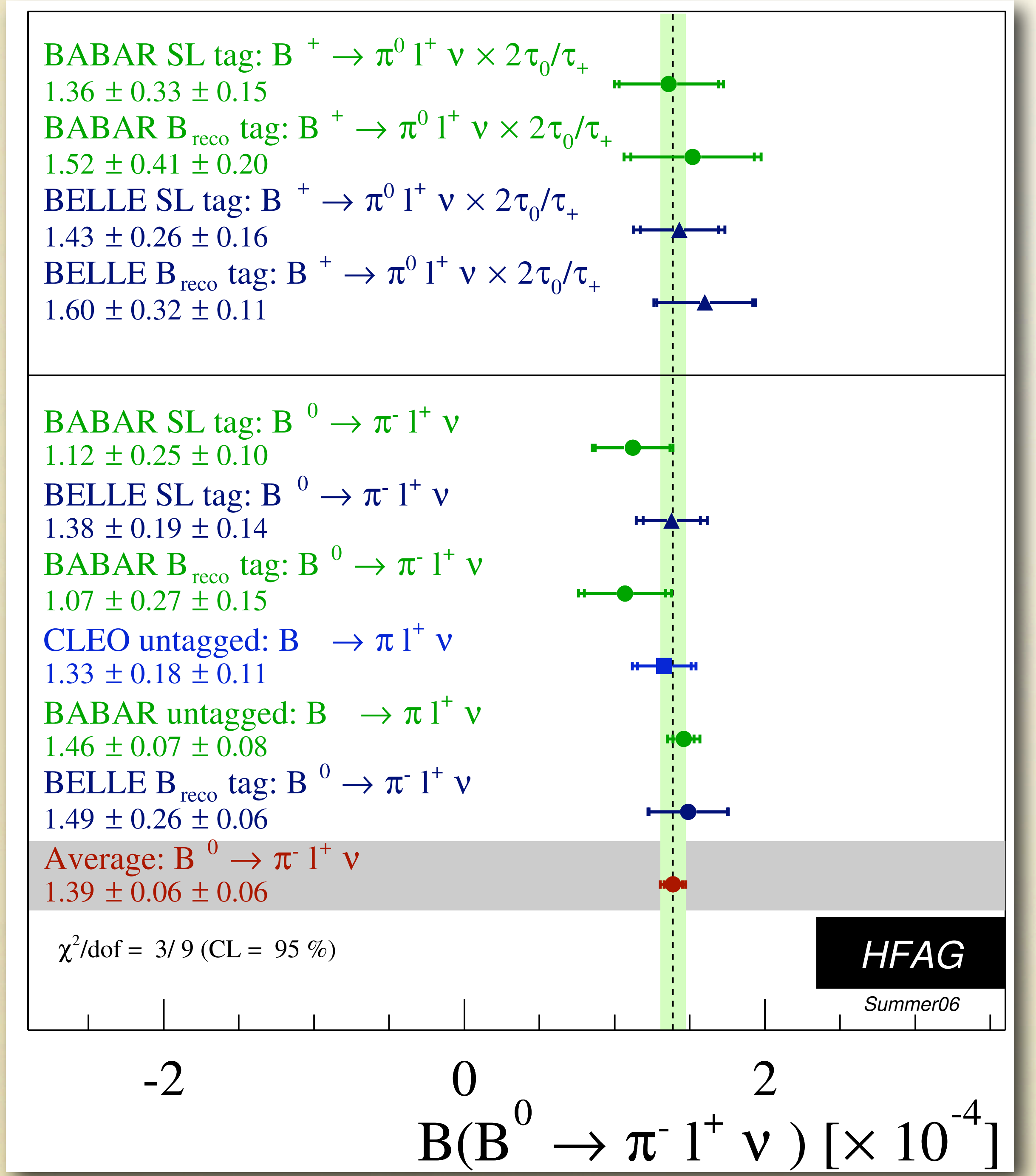
FIG. 1: Yield fit projections for (a,b) m_{ES} with $-0.16 < \Delta E < 0.20$ GeV; and (c,d) ΔE with $m_{\mathrm{ES}} > 5.272$ GeV. The

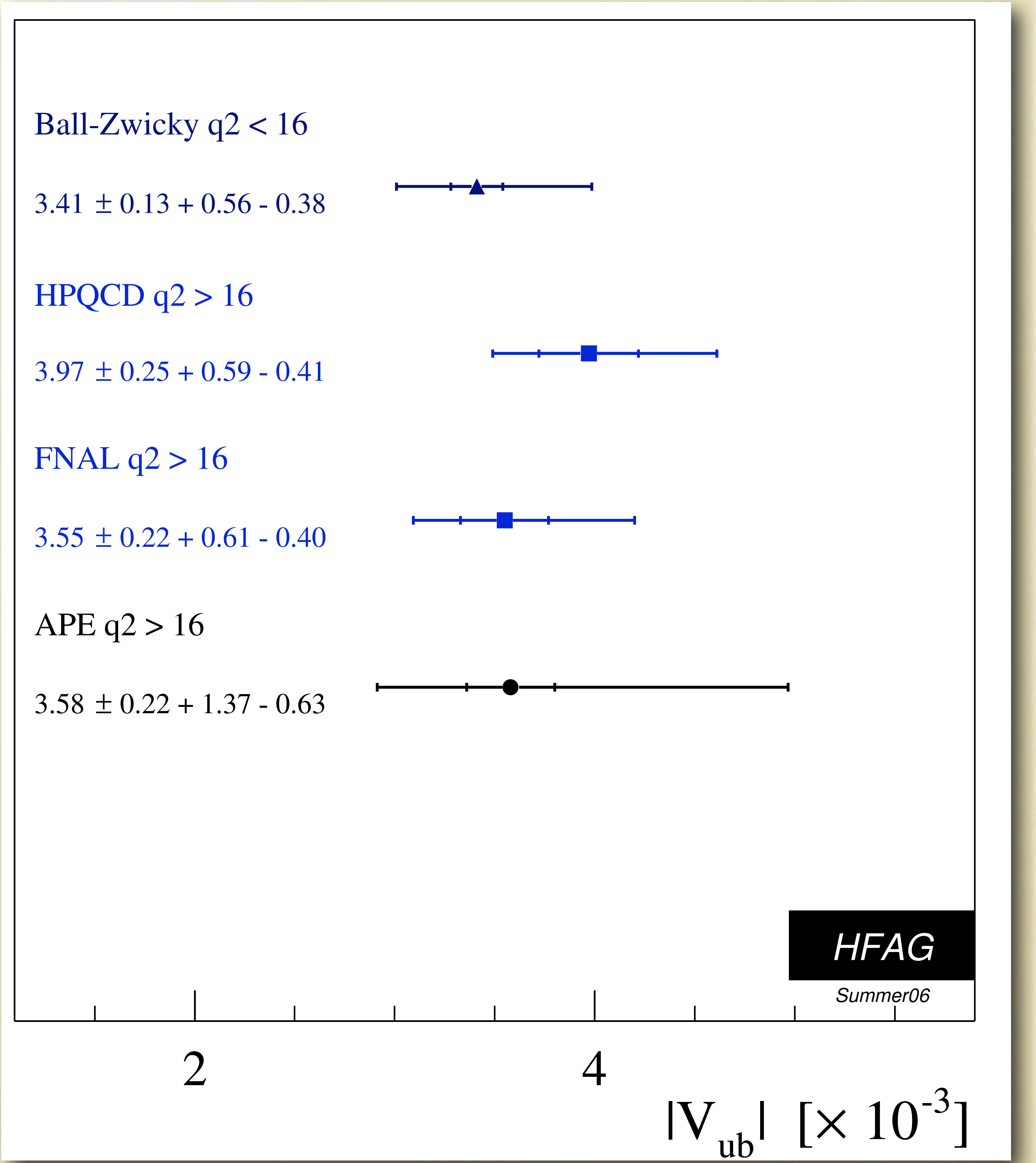




hep-ex/0612020 $|V_{ub}| = (4.1 \pm 0.2 \pm 0.2^{+0.6}_{-0.4}) \times 10^{-3}$ on $q^2 > 16$; by HPQCD

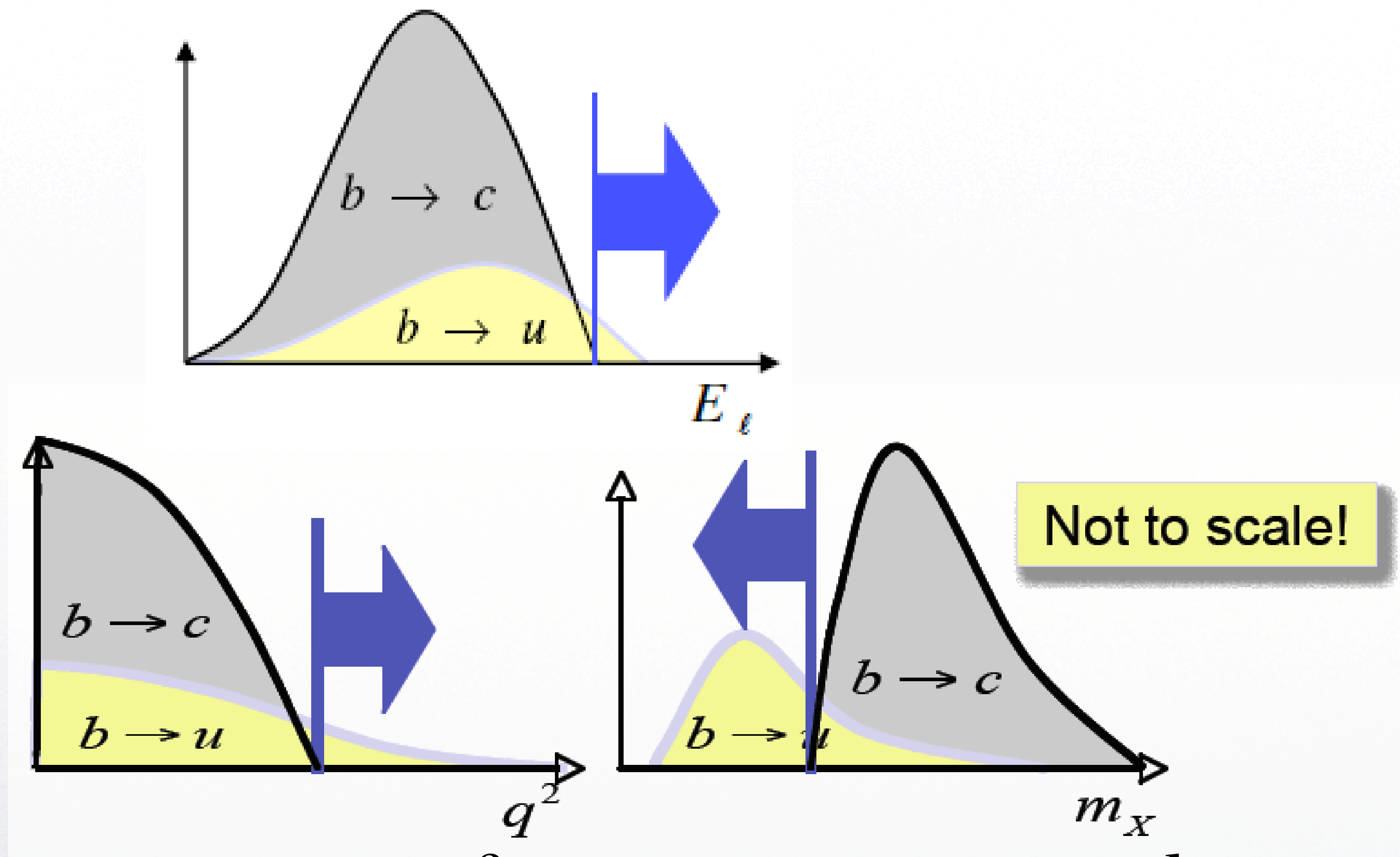
V_{ub} exclusive summary



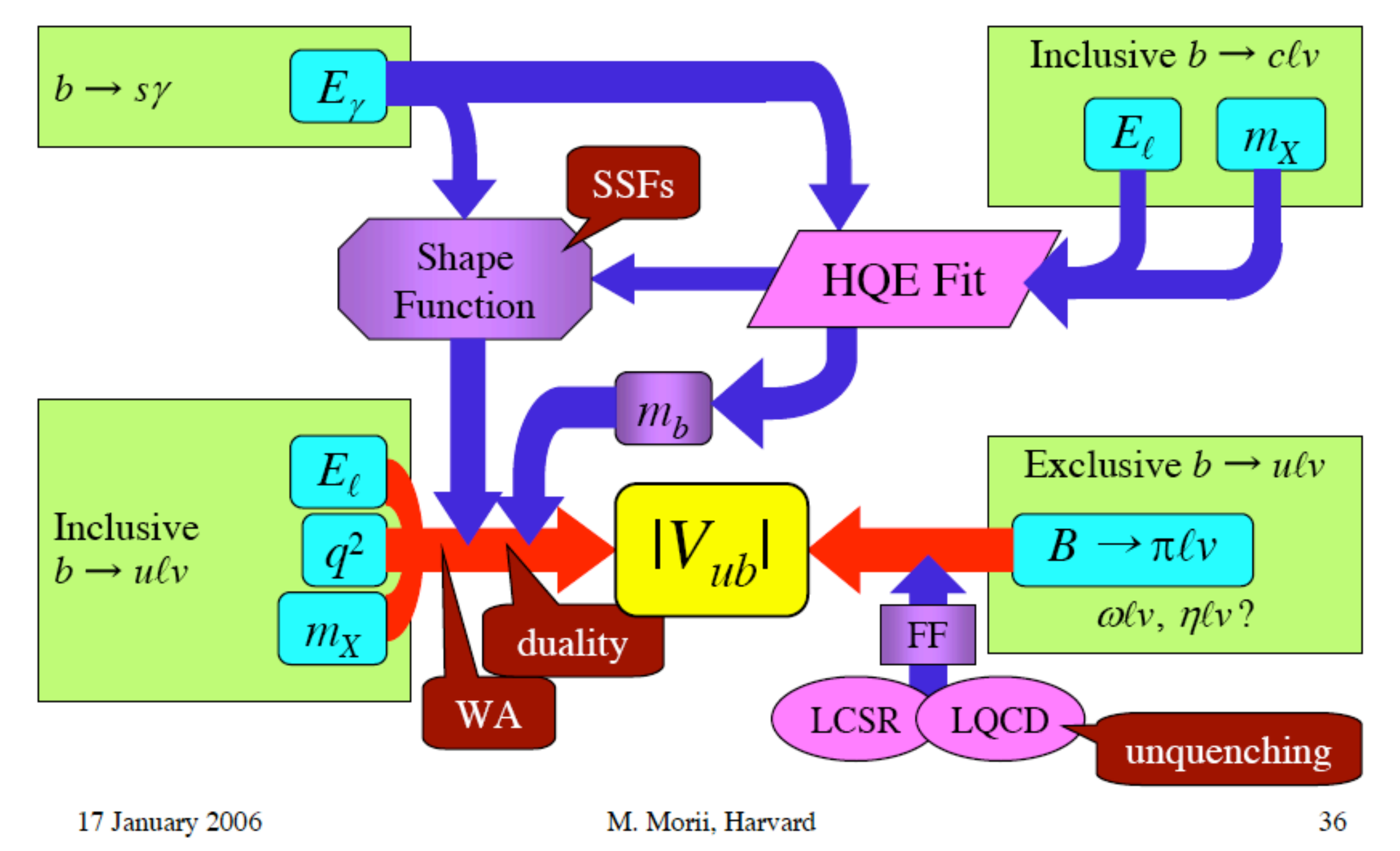


Experiments starting to measure form factor shape from data; allows elimination of some theory models

Inclusive $B \to X_u \ell \nu$



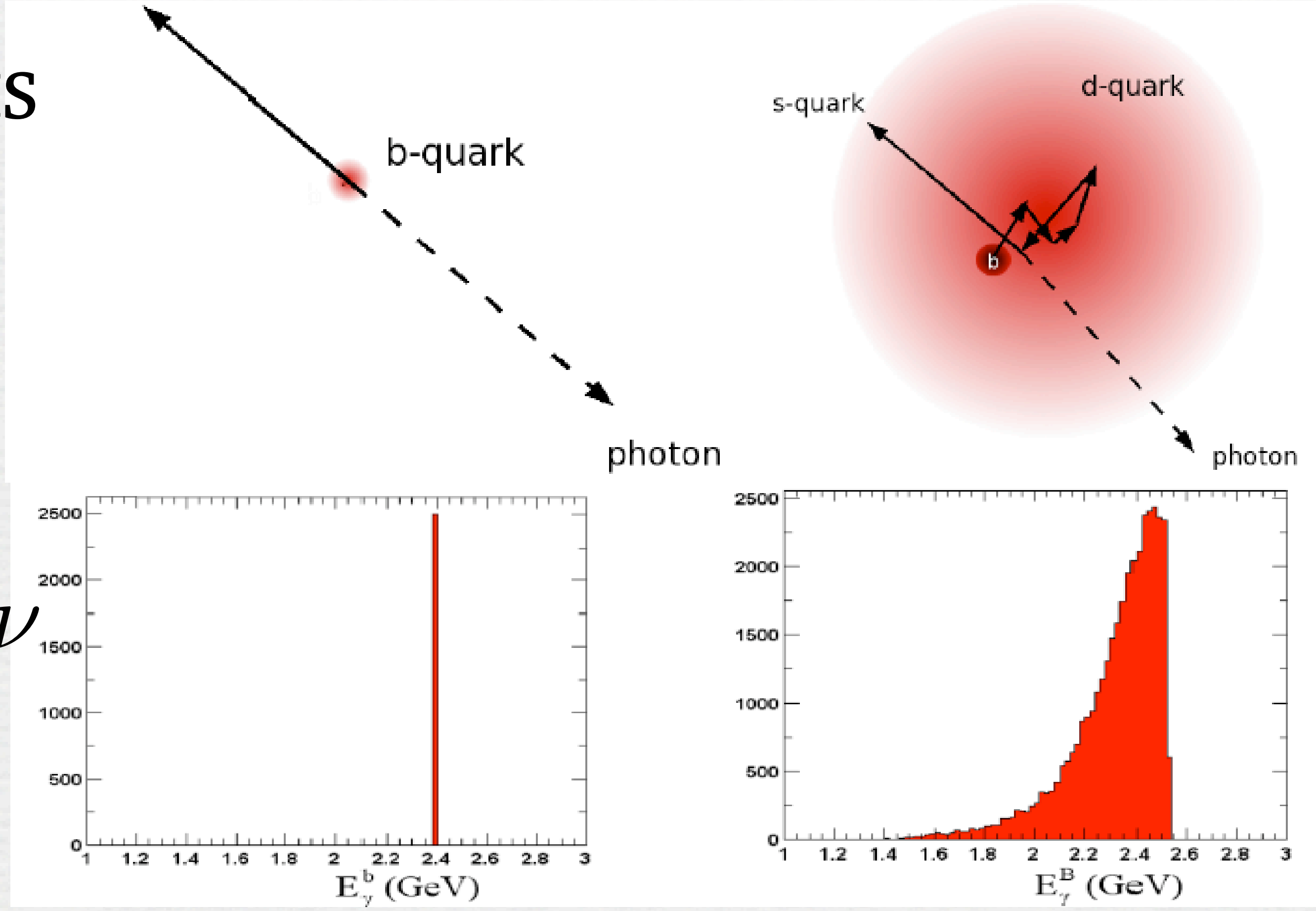
q^2 and M_x requires info. on missing ν --> how?



- Global quark-hadron duality
  - V_{cb} : excl. vs. incl. (OK)
- Weak annihil.
  - q^2 distorted ~ m_b^2
  - but, UL. from CLEO

$$\Gamma_{WA}/\Gamma_{b\to u} < 7.4\ \%$$

- need SF for non-pert. effects
- SF parameters
  - E_γ from $B \to X_s\gamma$
  - E_ℓ, M_X from $B \to X\ell\nu$
- sub-leading SF?

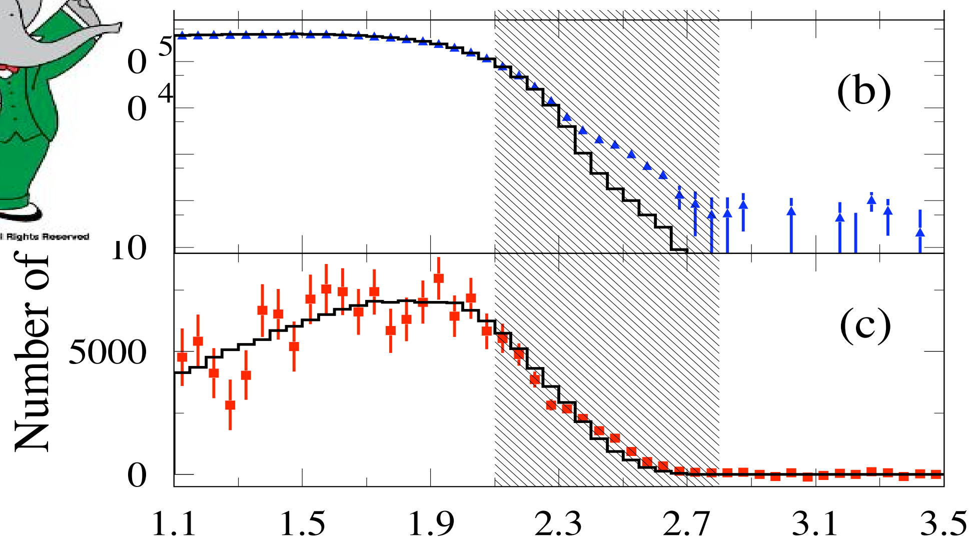


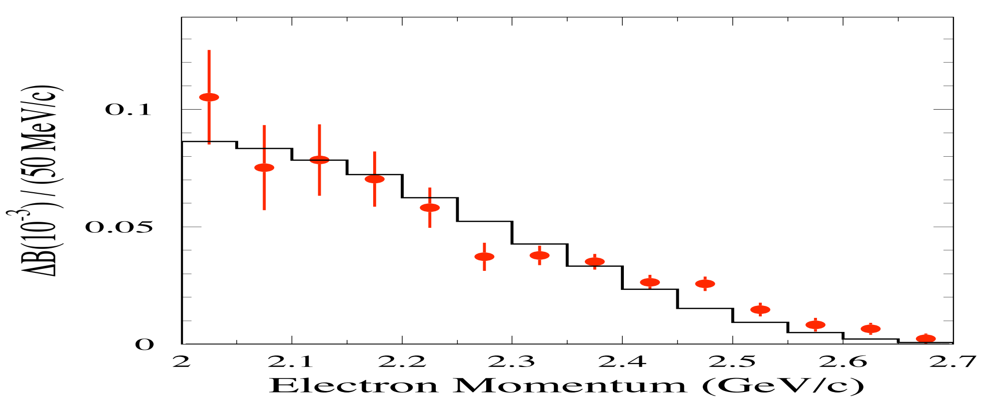
V_{ub} from Inclusive Methods

- endpoint of E(lepton)
  - using SF parameters from moments
- tagged: for (Mx, q^2)
  - using SF parameters from moments
  - LLR ("weighted") -- reduced dependence on SF

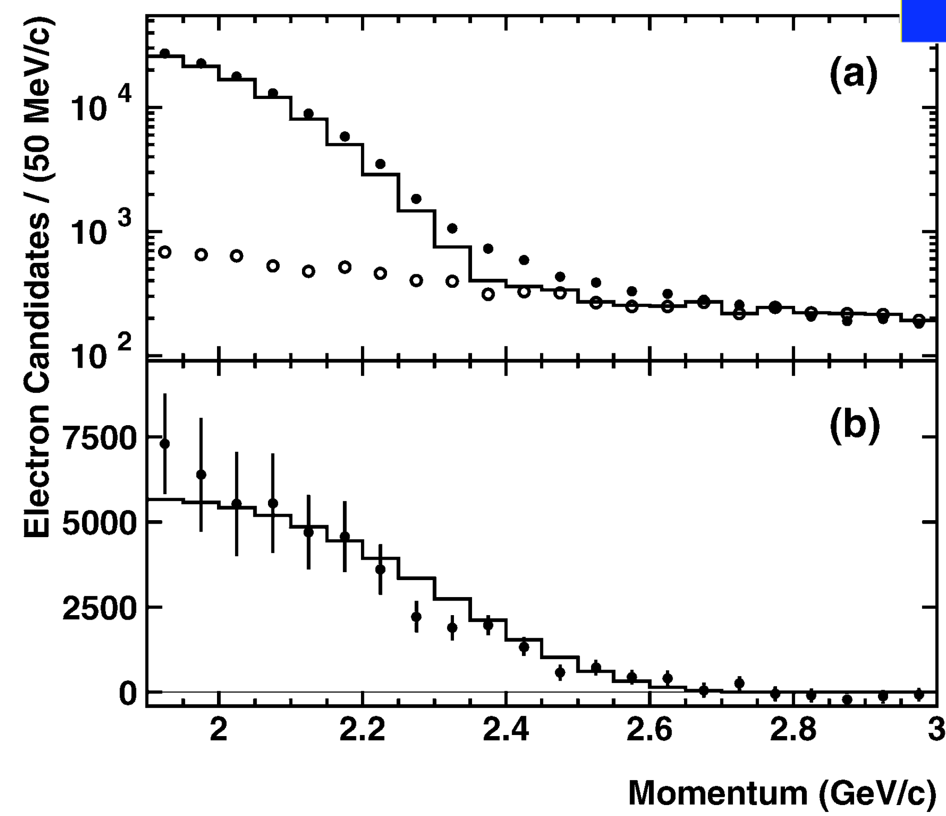
V_{ub} from Lepton End-point

PR D73, 012006 (2006)





PLB 621, 28 (2005)



$$\left(4.44 \pm 0.25^{+0.42}_{-0.38} \pm 0.22\right) \times 10^{-3}$$

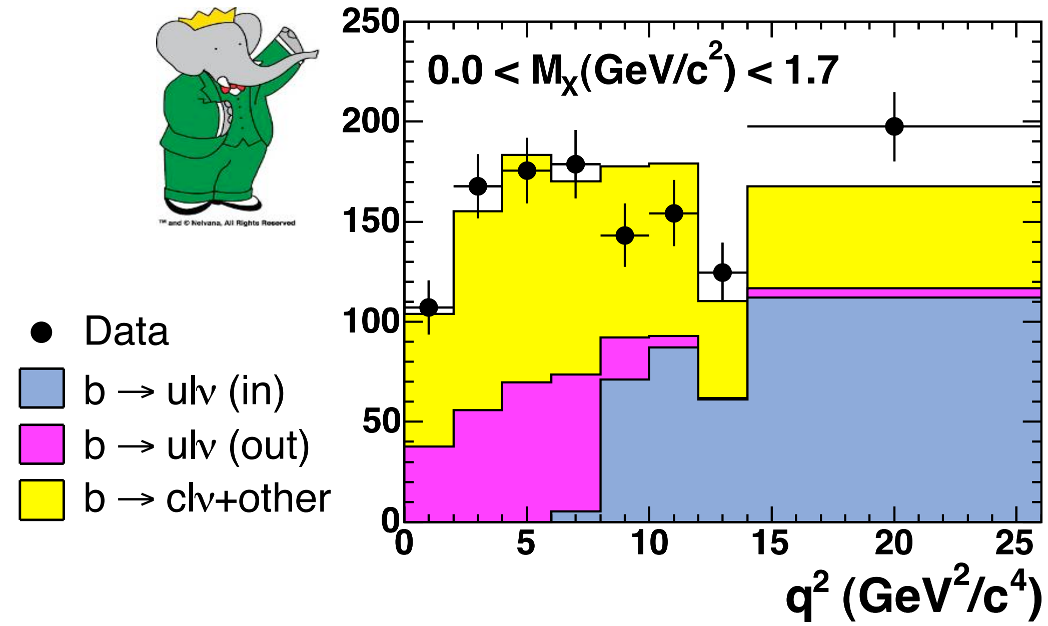
BLNP with $X_s\gamma$ and $X_c\ell\nu$ moments

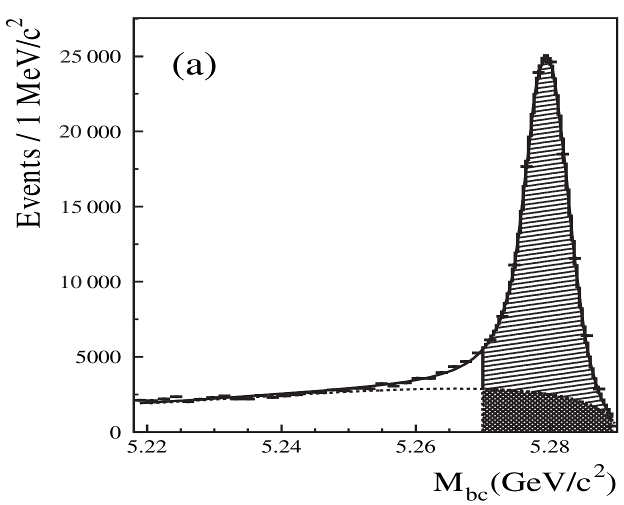
$$\left(5.08 \pm 0.47 \pm 0.42^{+0.26}_{-0.23}\right) \times 10^{-3}$$

BLNP with $X_s\gamma$ moments

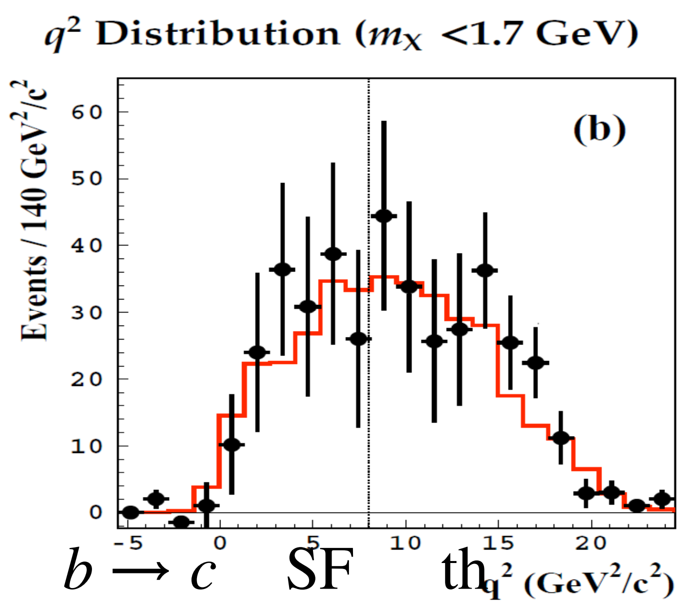
V_{ub} from Inclusive w/ (M_X, q^2)

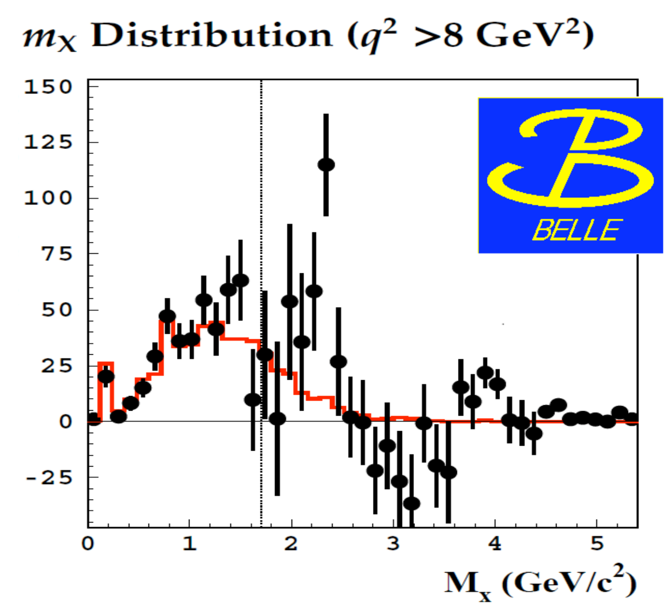
- Why cut on (M_X, q^2)?
  - high q^2: favorable for OPE
  - low M_X: controls $1/m_c^3$ blow-out
- use Full-recon. tagging





$$|V_{ub}|^{\rm BLNP}_{{\rm Belle}\ B\to X_s\gamma} = (5.00 \pm 0.27_{\rm stat} \pm 0.26_{\rm syst} \pm 0.46_{\rm SF} \pm 0.28_{\rm th}) \times 10^{-3},$$
$$|V_{ub}|^{\rm BLNP}_{BABAR\ b\to c\ell\bar\nu} = (4.65 \pm 0.24_{\rm stat} \pm 0.24_{\rm syst}{}^{+0.46}_{-0.38\,\rm SF} \pm 0.23_{\rm th}) \times 10^{-3},$$





$\Delta\Phi$	$\lvert V_{ub}\rvert \times 10^3$	Stat	Syst	$b \to u$	$b \to c$	SF	th
M_X/q^2	4.70	5.0	4.4	3.1	2.7	4.2	$^{+4.8}_{-5.2}$
M_X	4.09	4.6	3.5	3.1	1.1	4.5	$^{+3.5}_{-3.8}$

V_{ub} Inclusive (LLR method)

- m_{X_u} $(B \to X_u \ell \nu)$ and E_γ $(B \to X_s \gamma)$
- To reduce dependence on SF modelling
- two methods
  - ⋆ m_{X_u} in full range (U, HLM)
  - ⋆ $m_{X_u} < \zeta (< 1.67\ \mathrm{GeV})$ (LLR)

$$\Gamma(B \to X_u \ell \nu) = \frac{|V_{ub}|^2}{|V_{ts}|^2} \int W(E_\gamma) \frac{d\Gamma(B \to X_s \gamma)}{dE_\gamma} dE_\gamma$$

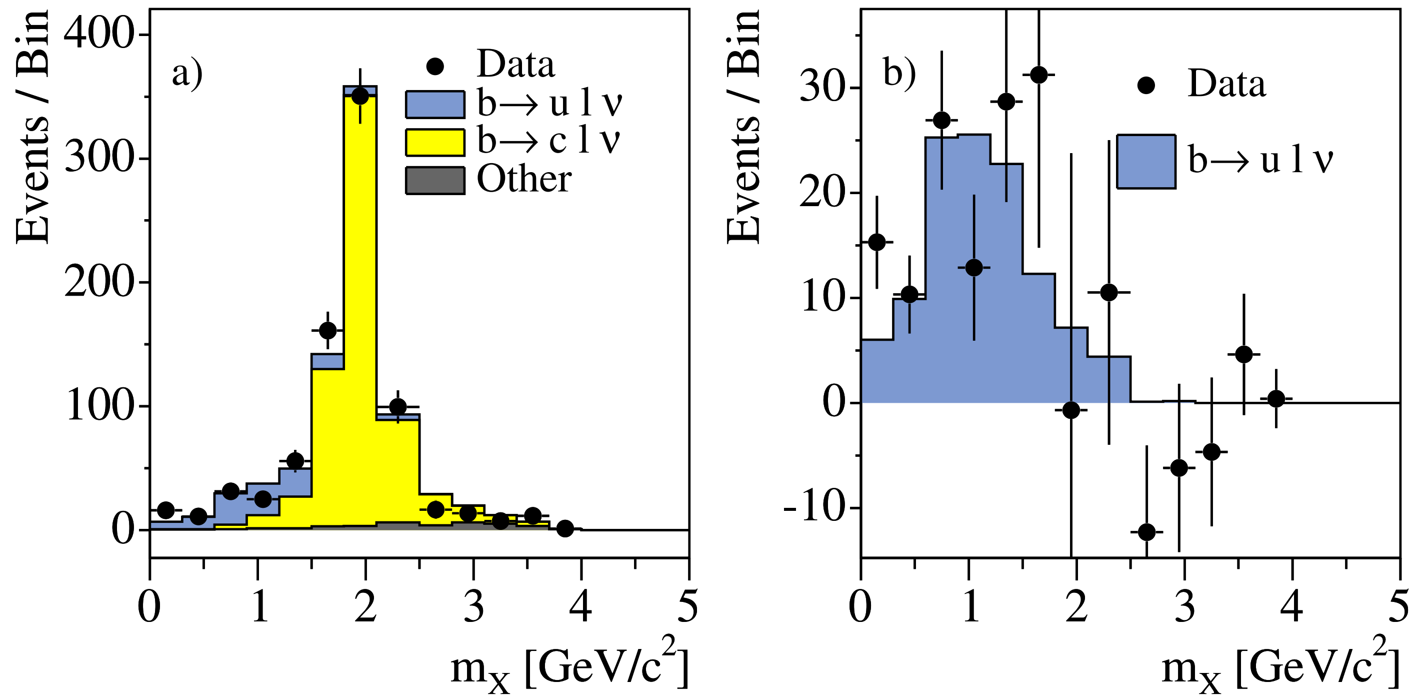
$$\frac{|V_{ub}|}{|V_{ts}|} = \left\{ \frac{6\alpha(1 + H^{\gamma}_{\mathrm{mix}})(C_7^{(0)})^2}{\pi[I_0(\zeta) + I_+(\zeta)]} \delta \mathcal{R}_u(\zeta) \right\}^{1/2}$$

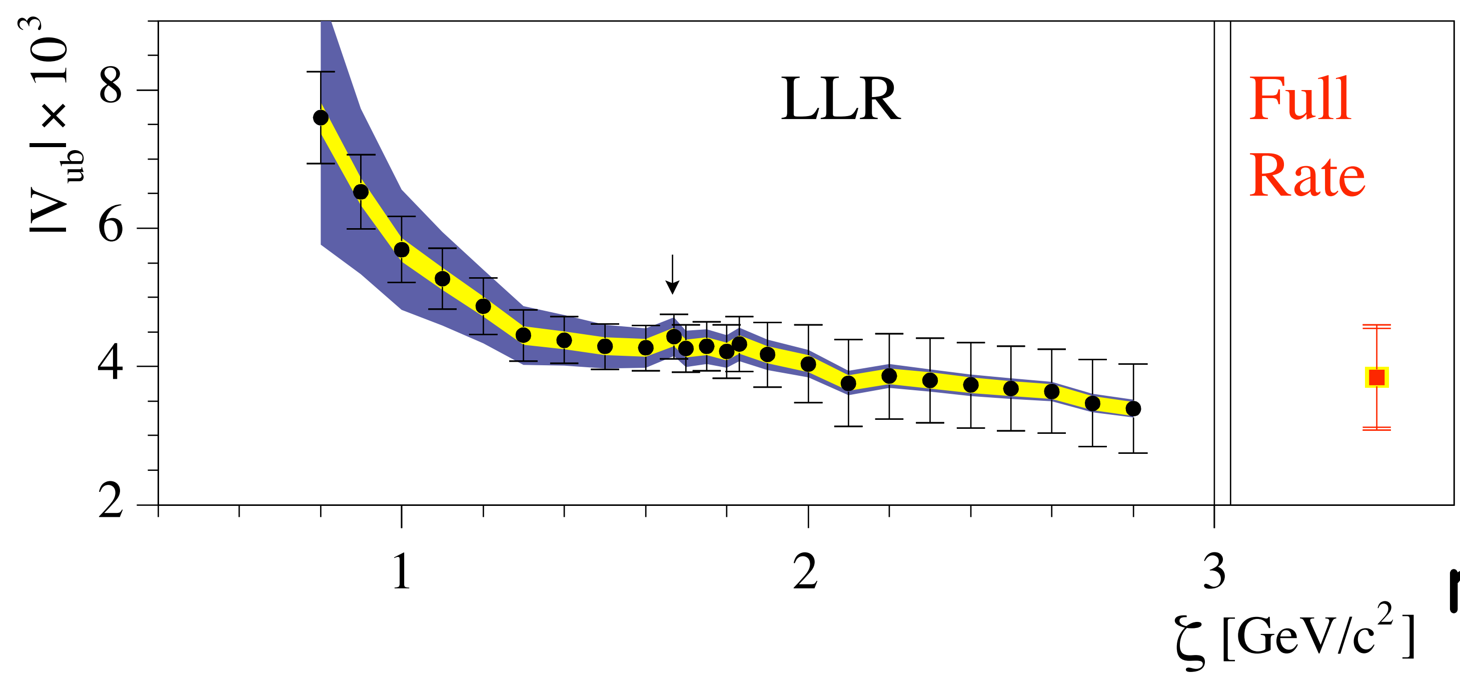
$$I_{0(+)}(\zeta) = \int_{g(\zeta)}^{1} dE_\gamma \frac{d\Gamma_{s\gamma}}{dE_\gamma} W_{0(+)}(E_\gamma)$$

$W_{0(+)}$: accurate up to $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}\left(\Lambda m_B / (\zeta m_b)\right)$

V_{ub} Inclusive (LLR method)

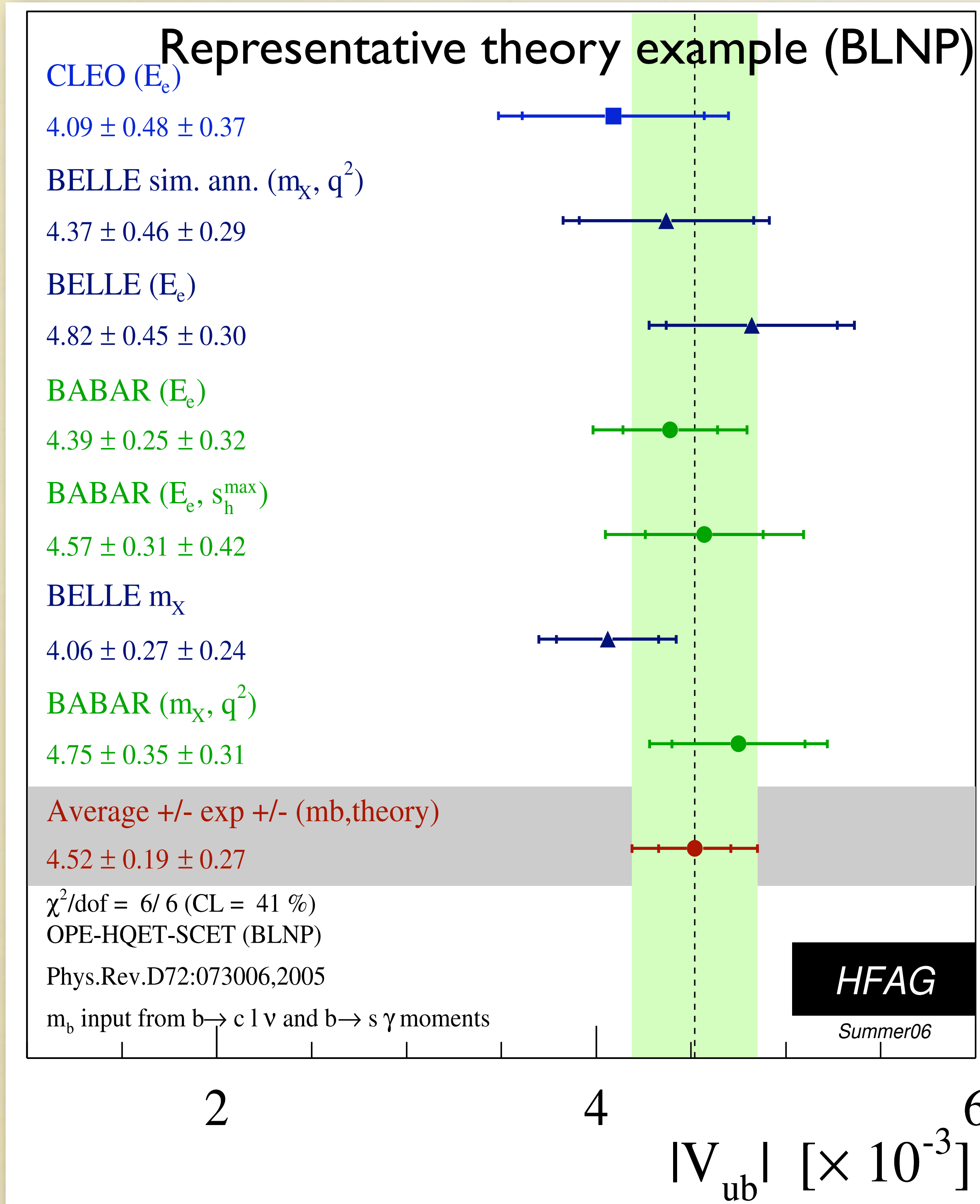
PRL 96, 221801 (2006)



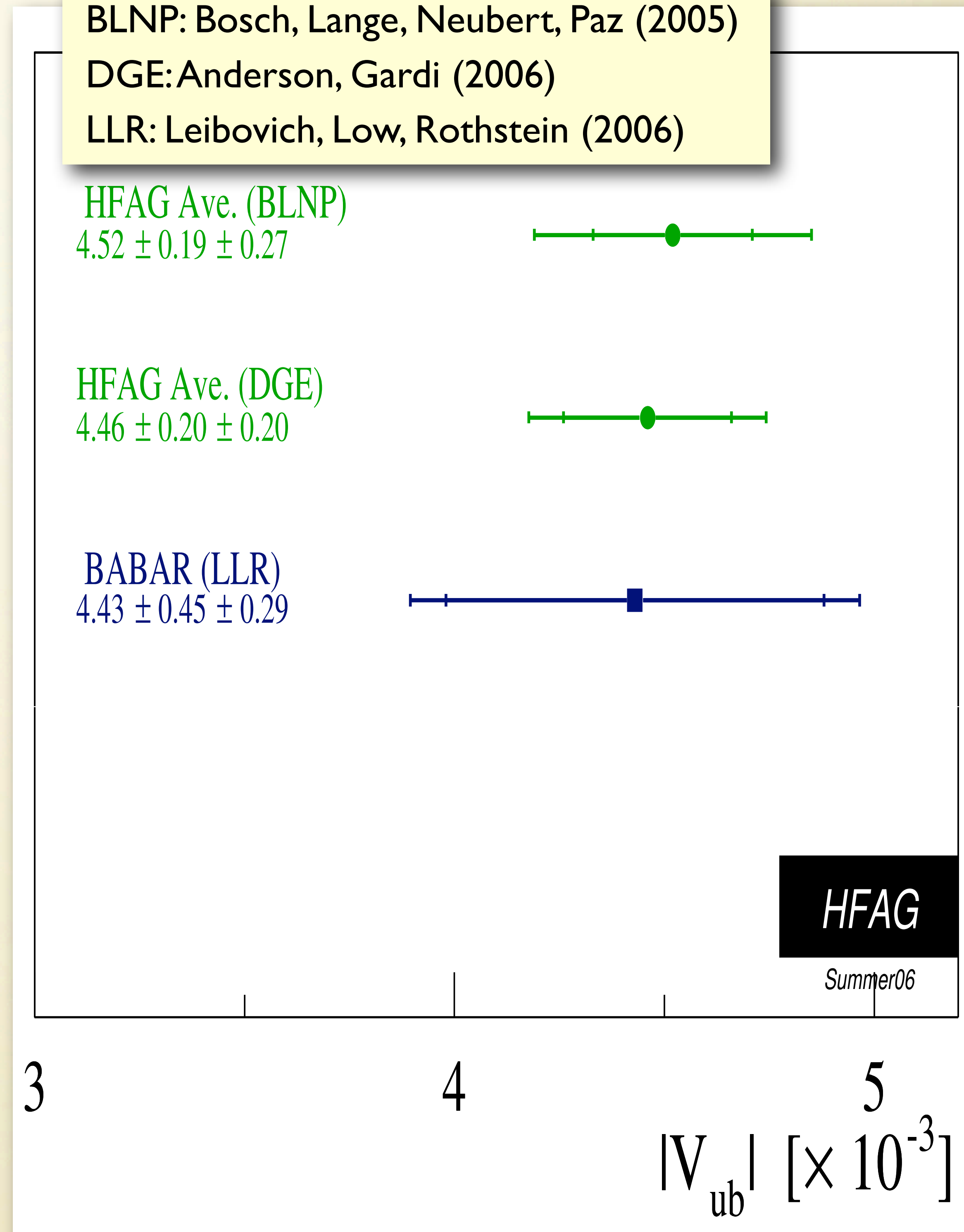


		m_X	accept.
LLR : M_X < 1.67 GeV:	$|V_{ub}| = (4.43 \pm 0.38_{stat} \pm 0.25_{syst} \pm 0.29_{theo})\ 10^{-3}$	12%	72%
OPE: M_X < 2.50 GeV:	$|V_{ub}| = (3.84 \pm 0.70_{stat} \pm 0.30_{syst} \pm 0.10_{theo})\ 10^{-3}$	20%	98%

V_{ub} inclusive summary



BLNP: Bosch, Lange, Neubert, Paz (2005)
DGE: Anderson, Gardi (2006)
LLR: Leibovich, Low, Rothstein (2006)



Summary

$$|V_{ub}|_{\text{incl}} = (4.52 \pm 0.19 \pm 0.27) \times 10^{-3}$$
$$|V_{ub}|_{\text{excl}} = (3.97 \pm 0.25^{+0.59}_{-0.41}) \times 10^{-3}$$

- V_{ub} from inclusive avg. give O(6%) error
  - restricted phase-space is much better understood
  - check with many complementary meas'mts.
- Exclusive analyses catch up
  - powerful B-tagging
  - improved ν-recon. --> fine-binned q2 dist. (BaBar)
  - unquenched L-QCD
- Systematics (esp. for SF param.) will improve with more statistics