4th SuperB Collaboration Meeting
La Biodola, 6-7 February 2012

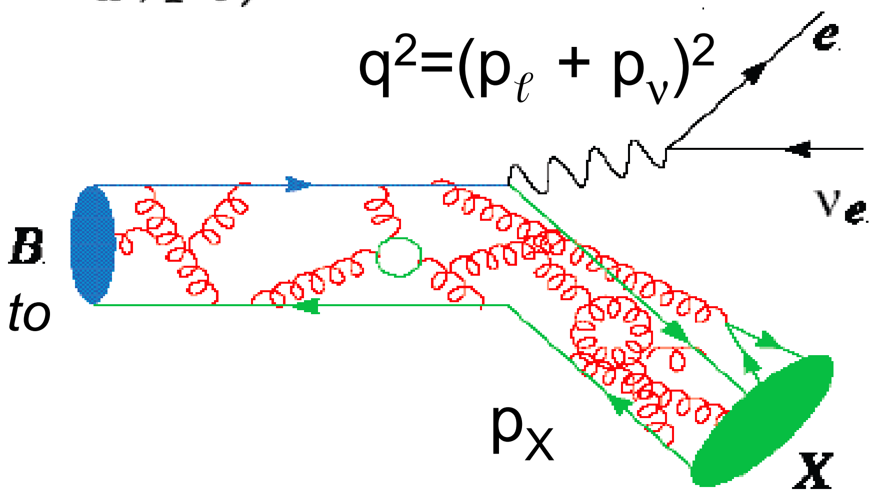
Experimental Status of $|V_{ub}|$ Measurements

Marcello Rotondo
(INFN Padova)

Semileptonic B decays: $|V_{ub}|$

- *Only one hadronic current:*

$$\Gamma(B \to \pi/X_u \ell\nu) = |V_{ub}|^2 \mathcal{F}^2(q^2, M_x, p_\ell)$$



$M_X = p_X^2$

Complementary Measurements

Exclusive decays ***$B\to \pi/\rho\, \ell\nu$*** *:*

- *QCD predictions of Form Factor required to parameterize hadronic effects*
- *Lattice QCD, LCSR...*

Inclusive decays ***$B\to X_u \ell\nu$*** *:*

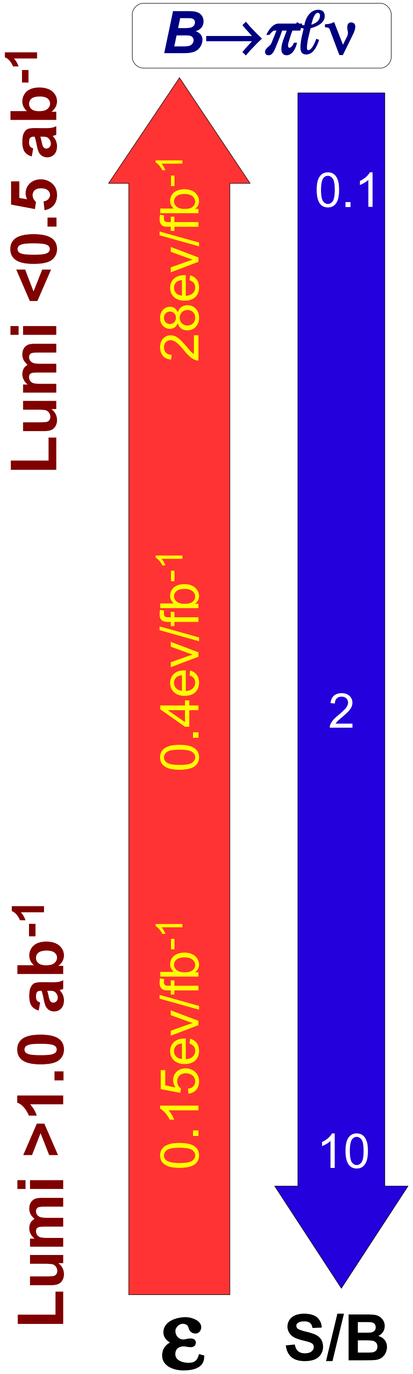
- *QCD corrections to parton level decay rate*
- *Need perturbative and non-perturbative corrections*
  - *4 approaches* ***BLNP***, ***DGE***, ***GGOU***, ***ADFR***
  - *Non-pert. parameters (m_c, m_b, μ_π^2) from $B\to X_c \ell \nu$ (and $B\to X_s\gamma$?)*

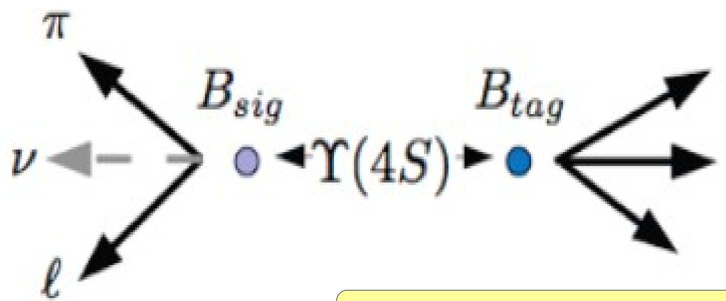
Neubert et al PRD72, 073006 (2005)
Gardi et al JHEP0601, 097 (2006)
Gambino et al JHEP0710, 058 (2007)
Aglietti et al EPJC 59, 831 (2009)

Exclusive decays

$B \to \pi \ell \nu$

B-Factory approach to B Excl-Semileptonics





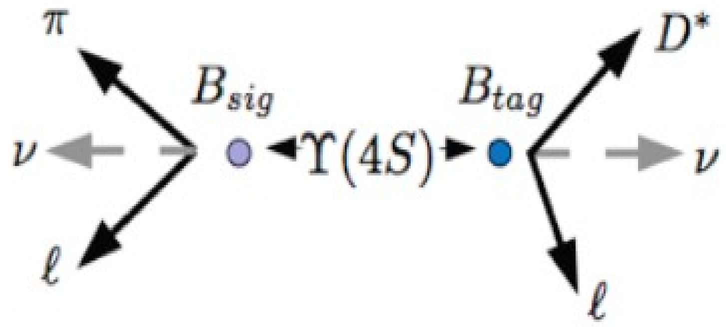
Rest used to reconstruct ν

Untagged

Initial momentum known

Missing 4-momentum = ν

Sensitive to bkg simulation

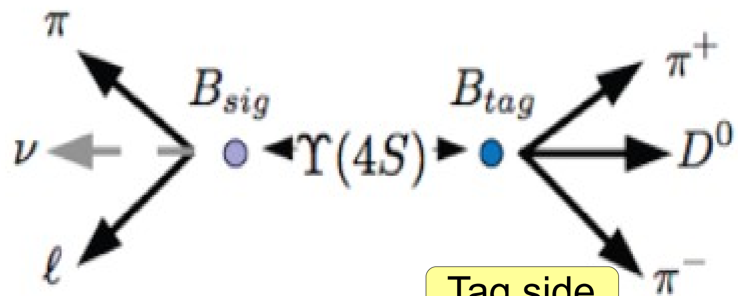


Tag side

Semileptonic Tag

One B reconstructed in D(*)ℓν

Two missing ν in event, the Kinematics is incomplete



Tag side

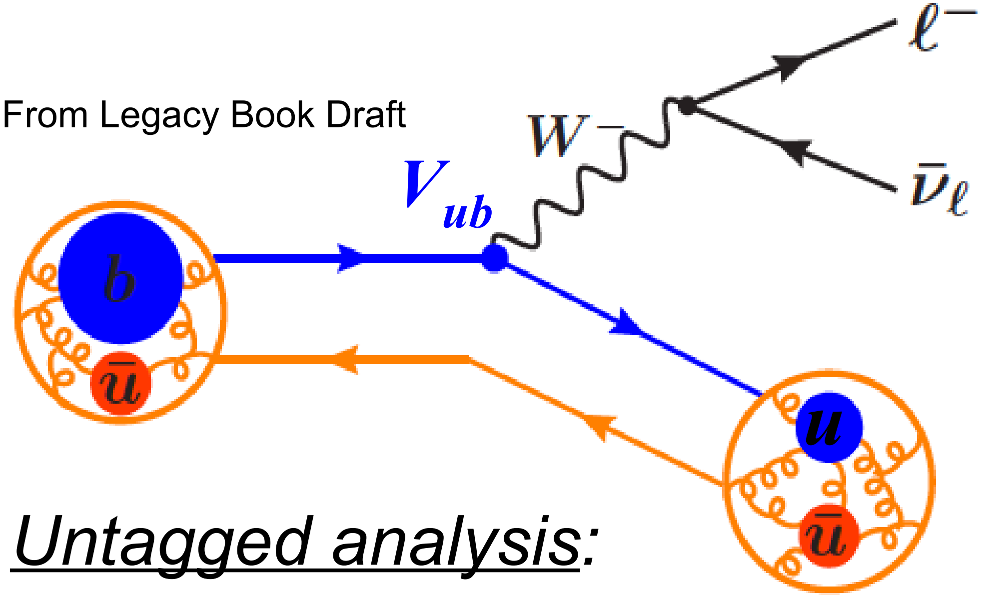
Full reconstruction Tag

One B reconstructed completely in know hadronic b→c modes

Closed kinematics

Exclusive $|V_{ub}|$ with $B\to\pi\ell\nu$

From Legacy Book Draft

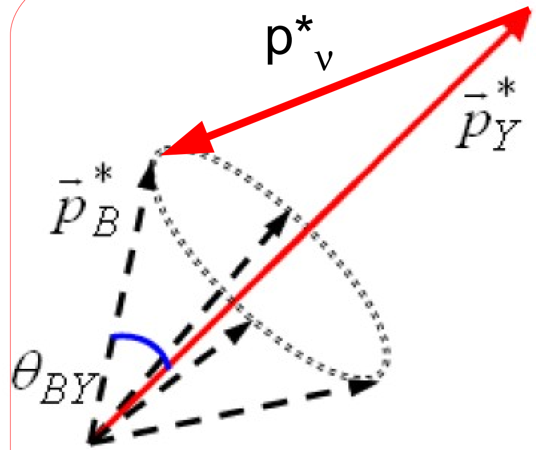


$$\frac{d\Gamma}{dq^2}(B\to\pi l\nu)=\frac{G_F^2}{24\pi^3}p_\pi^3\,|V_{ub}|^2|f_+(q^2)|^2$$

- *Untagged analysis*:
  - *Reconstruct π + e/μ*
  - *Neutrino from the rest of the event*

$$p_\nu=(|\vec{p}_{\rm miss}|,\vec{p}_{\rm miss})\qquad q^2=(p_\ell+p_\nu)^2=(p_{\rm B}-p_\pi)^2$$

- *Measure the partial rate ΔBF in bins of q^2 to reduce model dependence*
- *Integrate the partial BF in limited q^2 regions to extract $|V_{ub}|$:*
  - *q^2<12 (16) GeV^2 LCSR, q^2>16 GeV^2 for L-QCD*



q^2 is calculated as weighted average along the cone: Y-average q^2

σ = 0.54 GeV^2

Exclusive $|V_{ub}|$ with $B\to\pi\ell\nu$

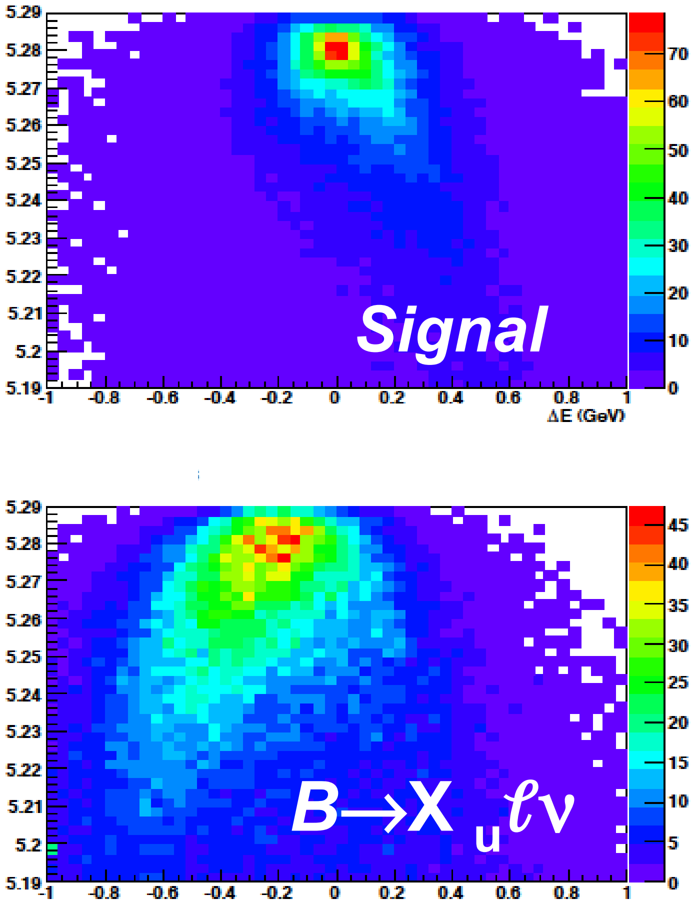
- Background reduced with q^2-dependent cuts or NN optimized in bins of q^2
- m_{ES}-ΔE fit to $\pi^+\ell\nu$
- BaBar: two analysis, 6 or 12 bins of q^2
- Belle: very similar to the BaBar 12 bins analysis

BaBar 6 bin:	**7181**(π^+)+**3446**(π^0)	349 fb^{-1}
BaBar 12 bin:	**11788** (π^+)	422 fb^{-1}
BaBar 13 bin:	**21486** (π^+)	605 fb^{-1}

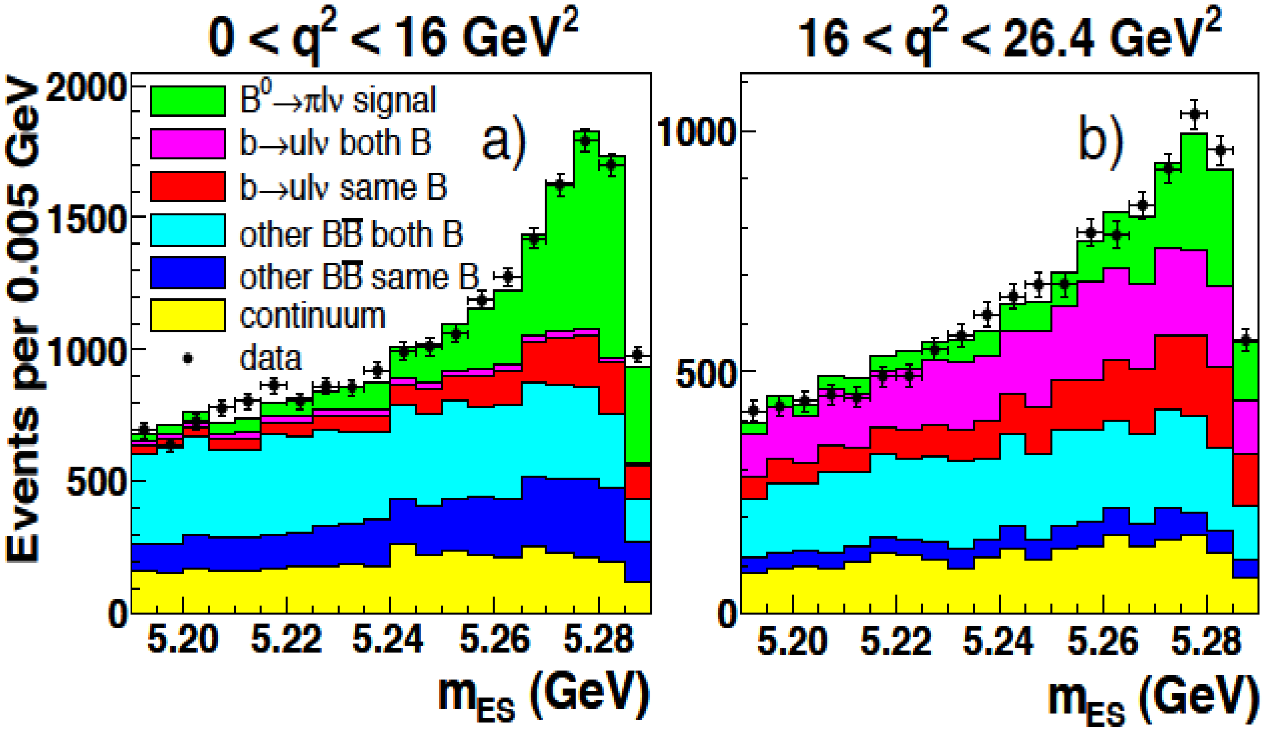
BaBar 12: fit background components in q^2 bins

- 12 bins for the signal
- 2 for the X_u and X_c backgrounds
- 2 for the continuum

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

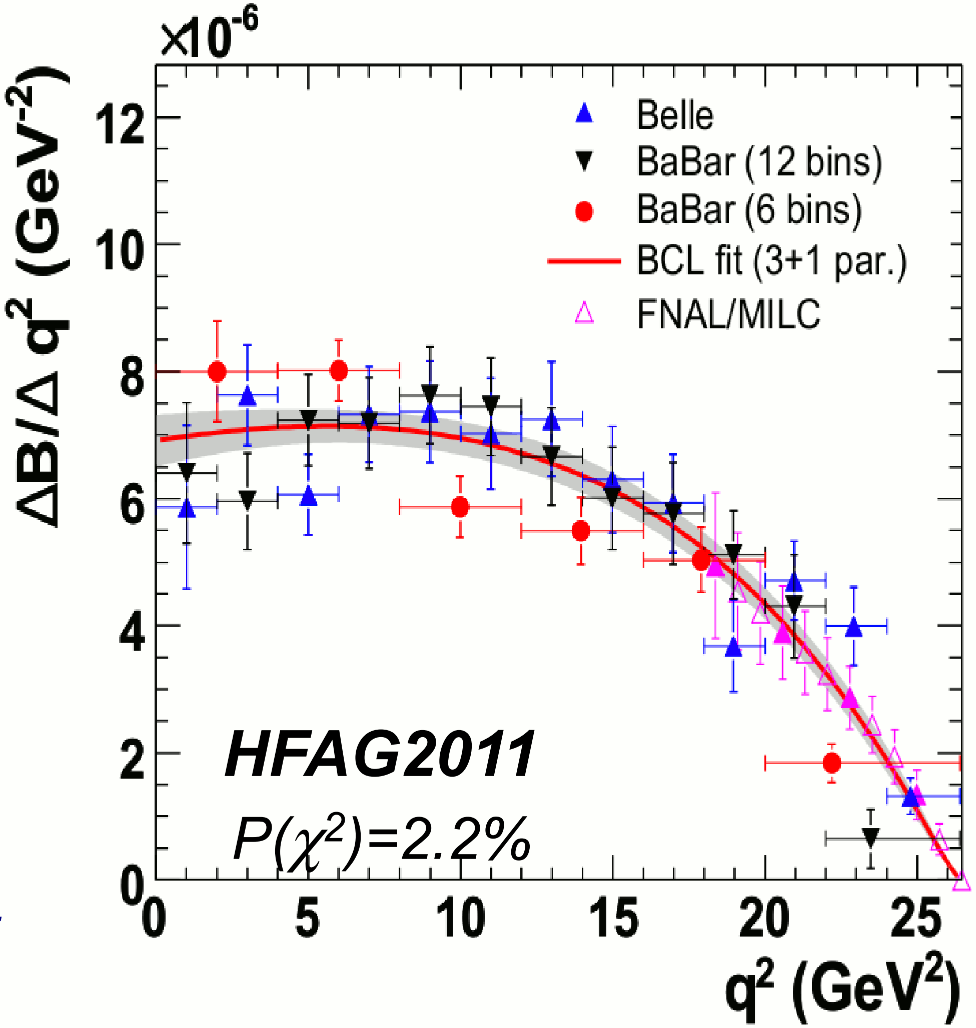


$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$



Untagged $B \to \pi^{+/0} \ell \nu$

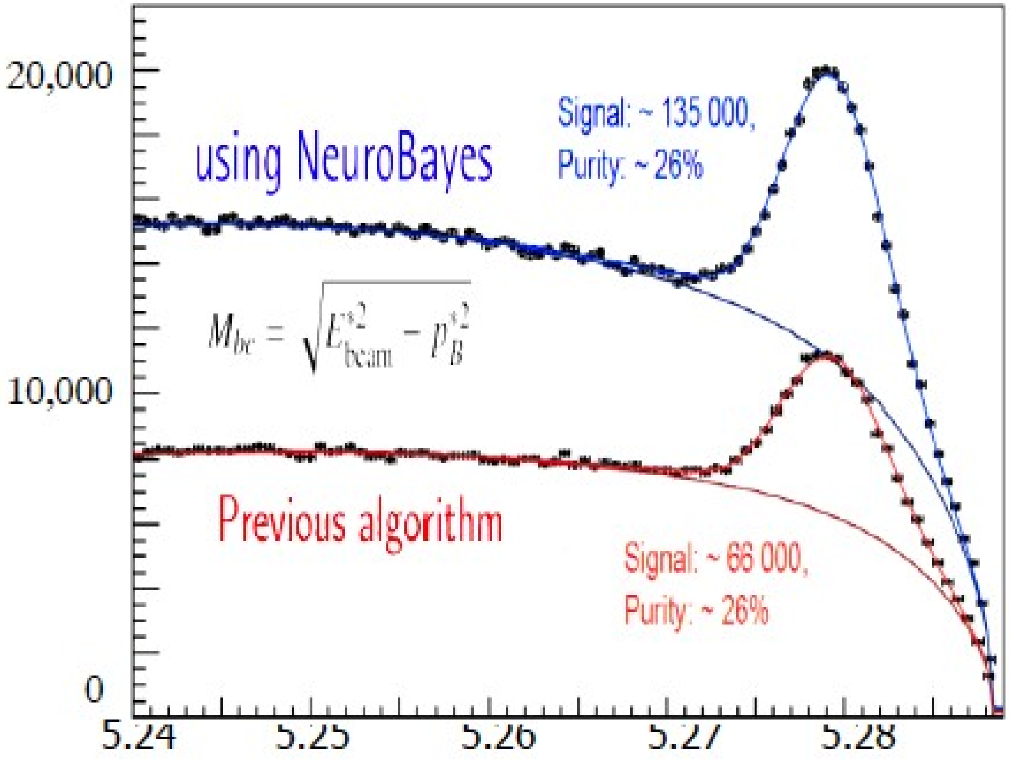
- $|V_{ub}|$ extracted from a combined fit to data and LQCD predictions
  - Based on BCL expansion Phys. Rev. D79, 013008 (2009)
- Experimental and theoretical errors reduced:
  - Measured spectrum constrain the FF shape
  - LQCD provides normalization (used 6 out of the 12 available points !)
- Combined fit to Belle and BaBar data:
  - $|V_{ub}|=(3.23\pm0.18_{exp}\pm0.24_{th})\cdot10^{-3}$
- 9% uncertainty!
- Error budget:
  - ~4% from q^2 shape and ~7.5% from FF normalization



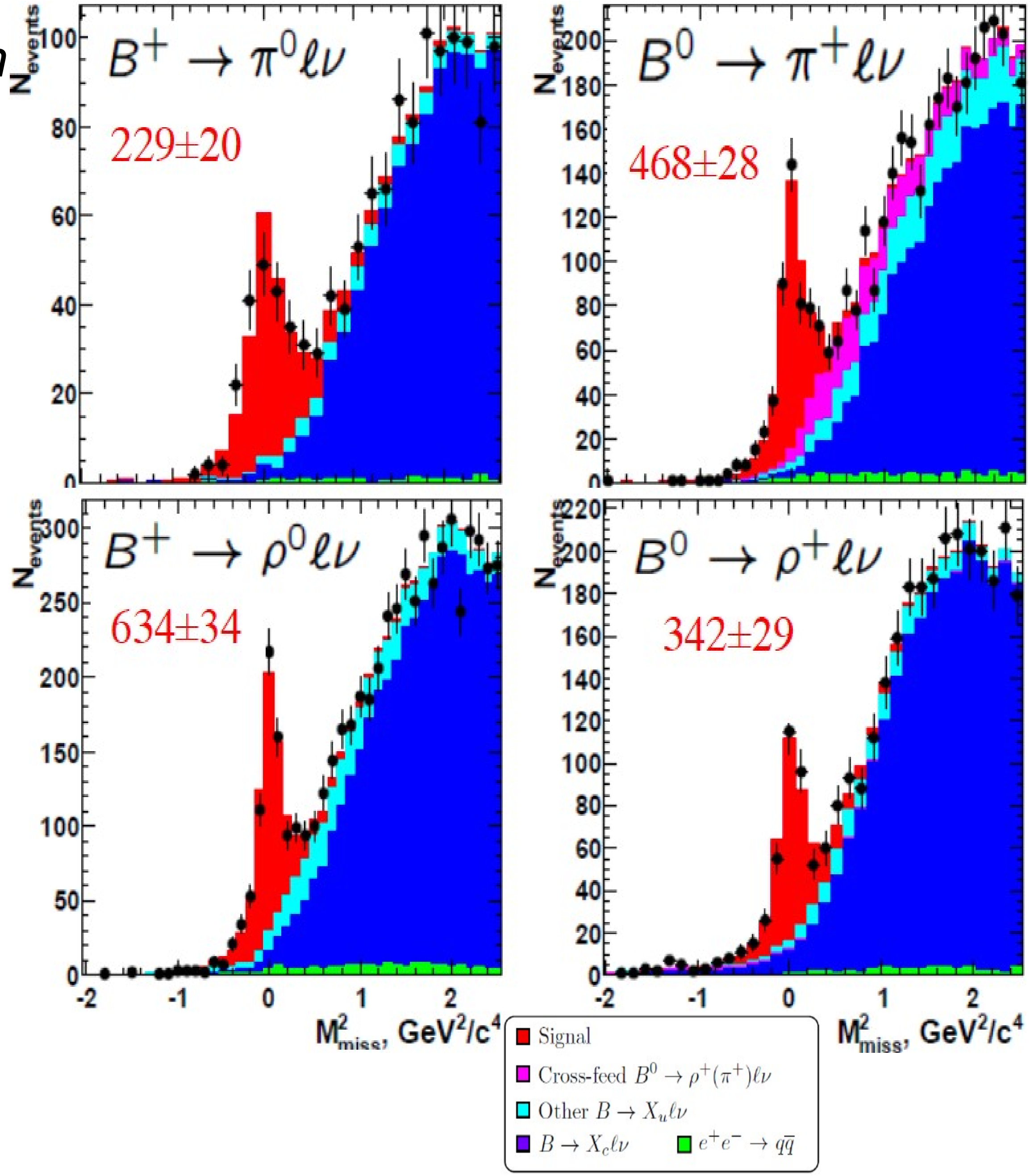
- Compatible with $|V_{ub}|$ extracted from integrated q^2 regions with FF from LCSR and L-QCD

Belle: with $B \to h\ell\nu$ with Hadronic Tags

- *Full Y(4S) data set 710/fb*
- *New hadronic tag procedure with gain 2x with P=26%*
  - *Based on NeuroBayes©*



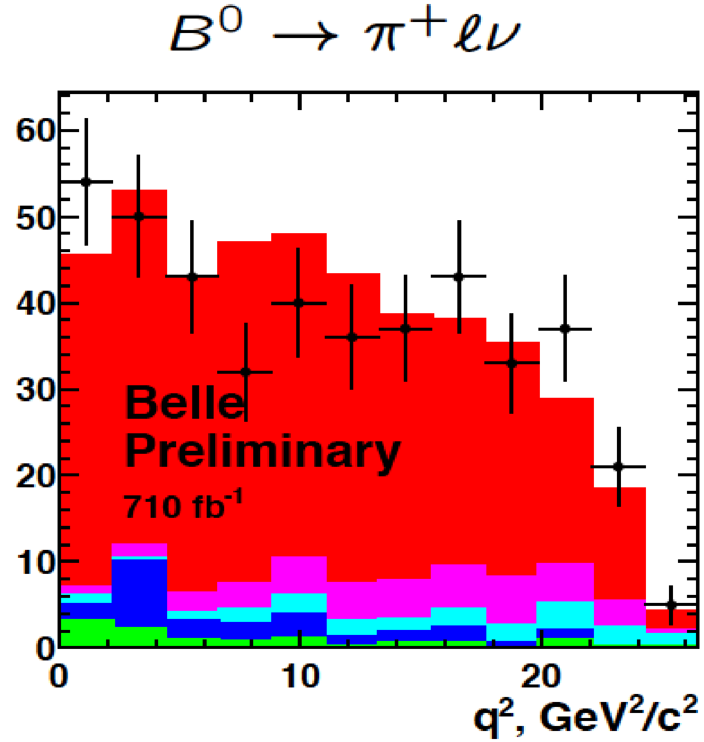
Belle preliminary (Lake Luise'12)



- *Signal extracted from EML fit of the M2miss distribution*
- *Also $B \to (\omega,\eta,\eta')\ell\nu$*

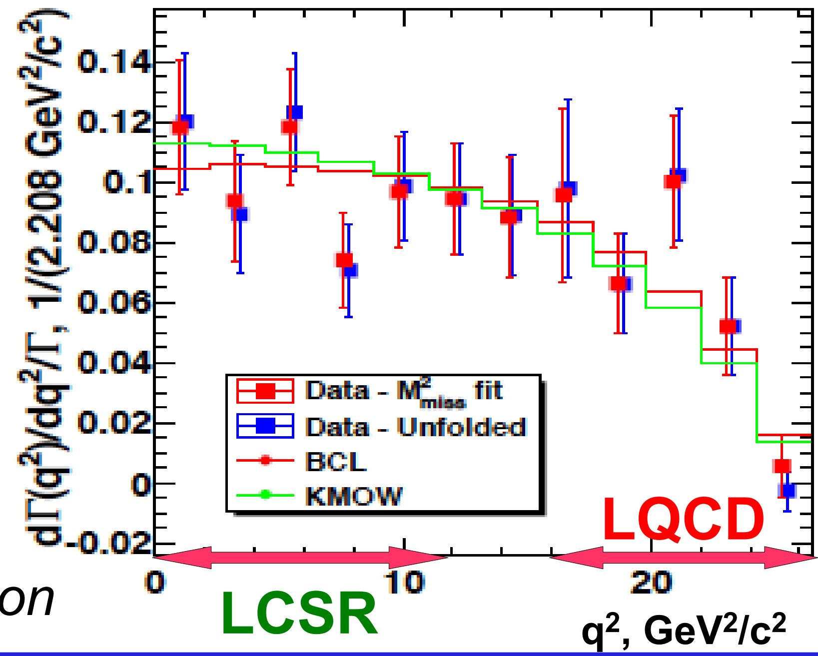
Belle: with $B\to\pi\ell\nu$ with Hadronic Tags

- *Improved hadronic tags open new opportunities*
  - *Very clean sizable samples*
  - *First look at q^2 dependence in many bins*
  - *Small background at high q^2*
  - *Loose cuts on signal: small model signal and background model dependence*
  - *Results agree very well with untagged measurements*



X_u	Theory	q^2 [GeV^2]	$\lvert V_{ub}\rvert \times 10^{-3}$
	KMOW[1]	<12	$3.38 \pm 0.14 \pm 0.09^{+0.37}_{-0.31}$
π^+	Ball/Zwicky[2]	<16	$3.57 \pm 0.13 \pm 0.09^{+0.47}_{-0.47}$
	FNAL[3]	>16	$3.69 \pm 0.22 \pm 0.09^{+0.39}_{-0.35}$
	HPQCD[4]	>16	$3.86 \pm 0.23 \pm 0.10^{+0.53}_{-0.53}$

- *Improved hadronic tags open new opportunities*
- *Ongoing work to fit spectrum*
  - *Larger systematics (5-7%) due to the normalization*



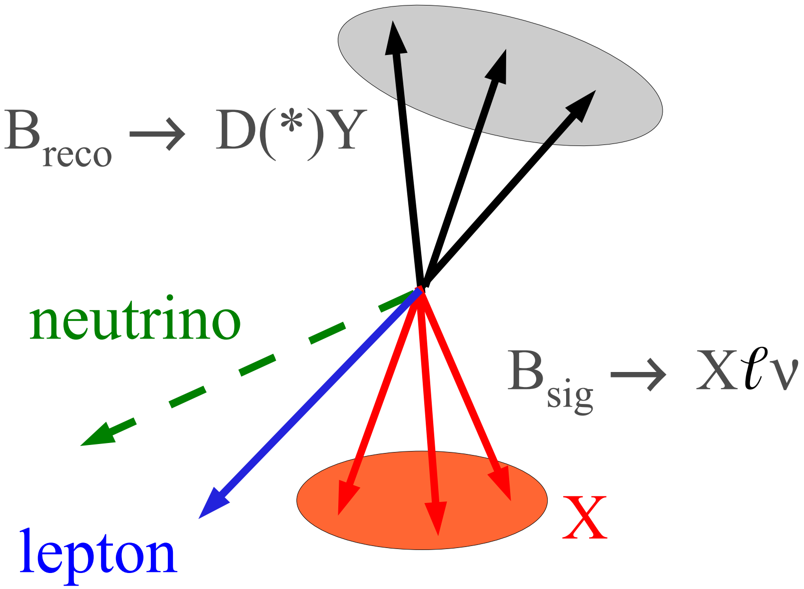
Inclusive decays

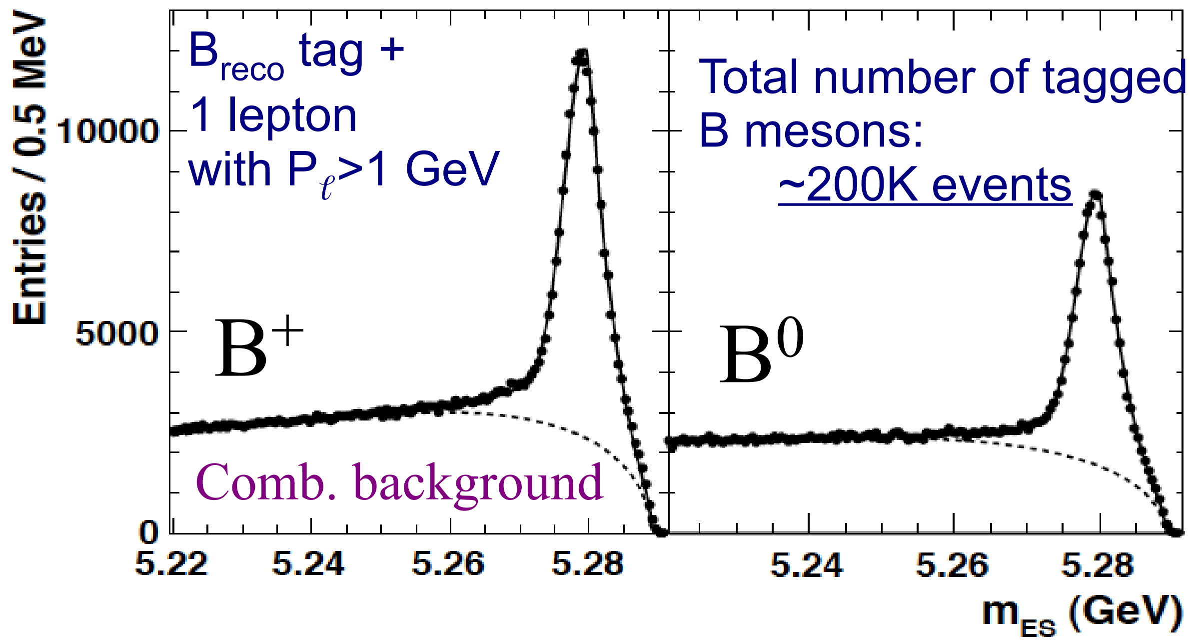
$B \to X_u \ell \nu$

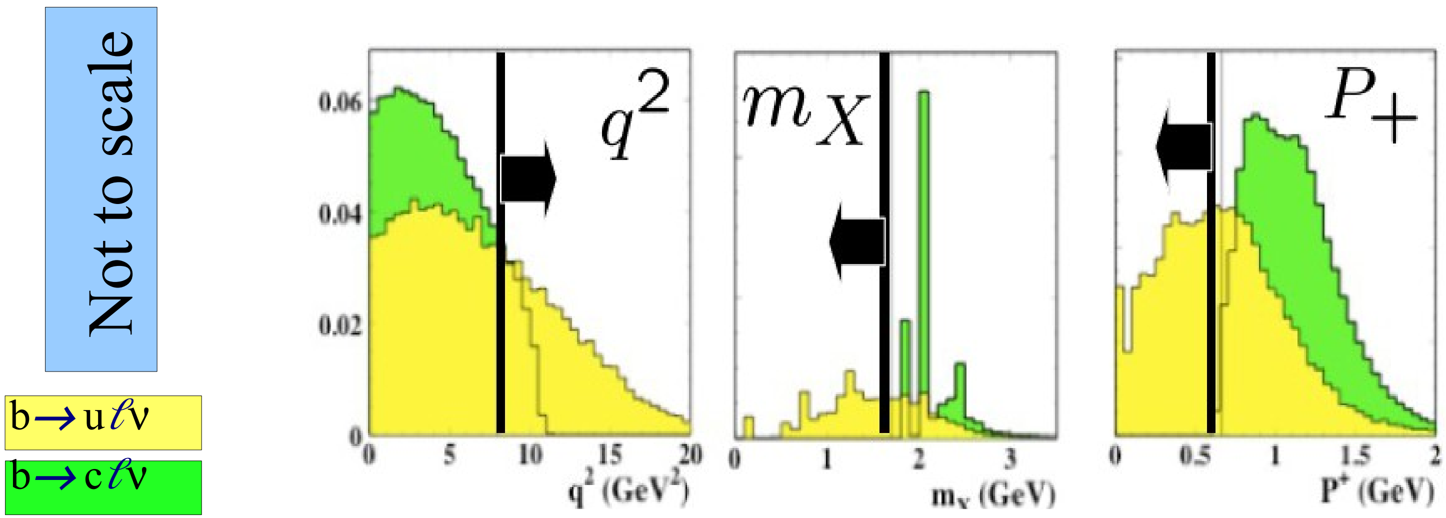
$|V_{ub}|$ From Inclusive $B \to X_u \ell\nu$

- ▶ *Large background from $B \to X_c \ell\nu$:*
  - *Kinematics to extract the signal (lepton endpoint, $M_X < M_D$,...)*

Use hadronic tag $\boldsymbol{B_{tag} \to D^{(*)}Y}$ to reduce combinatorial and reconstruct M_X, q^2 and $P_+ = E_X - p_X$ with good resolution





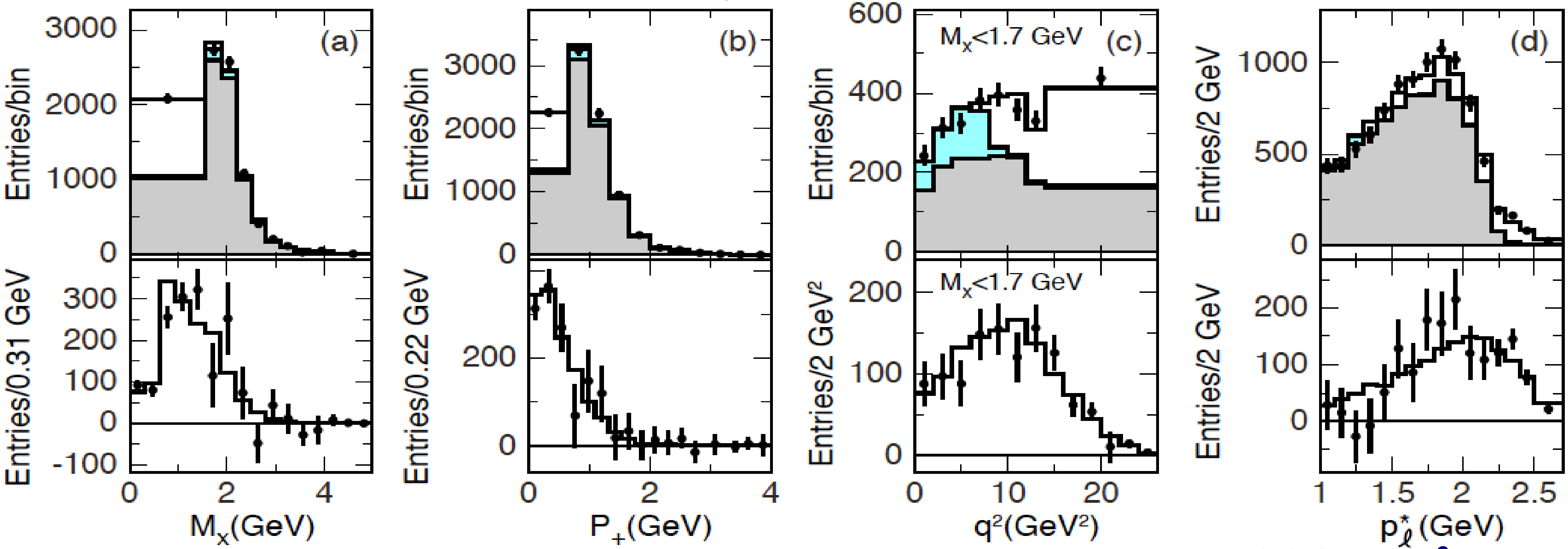


- *Experimental resolution leads to irreducible b c$\ell\nu$ contamination*

$|V_{ub}|$ From Inclusive $B \to X_u \ell \nu$

Veto $B \to D(*) \ell \nu$ with Kaons, soft pions, and missing mass

*D** fraction constrained from control samples*

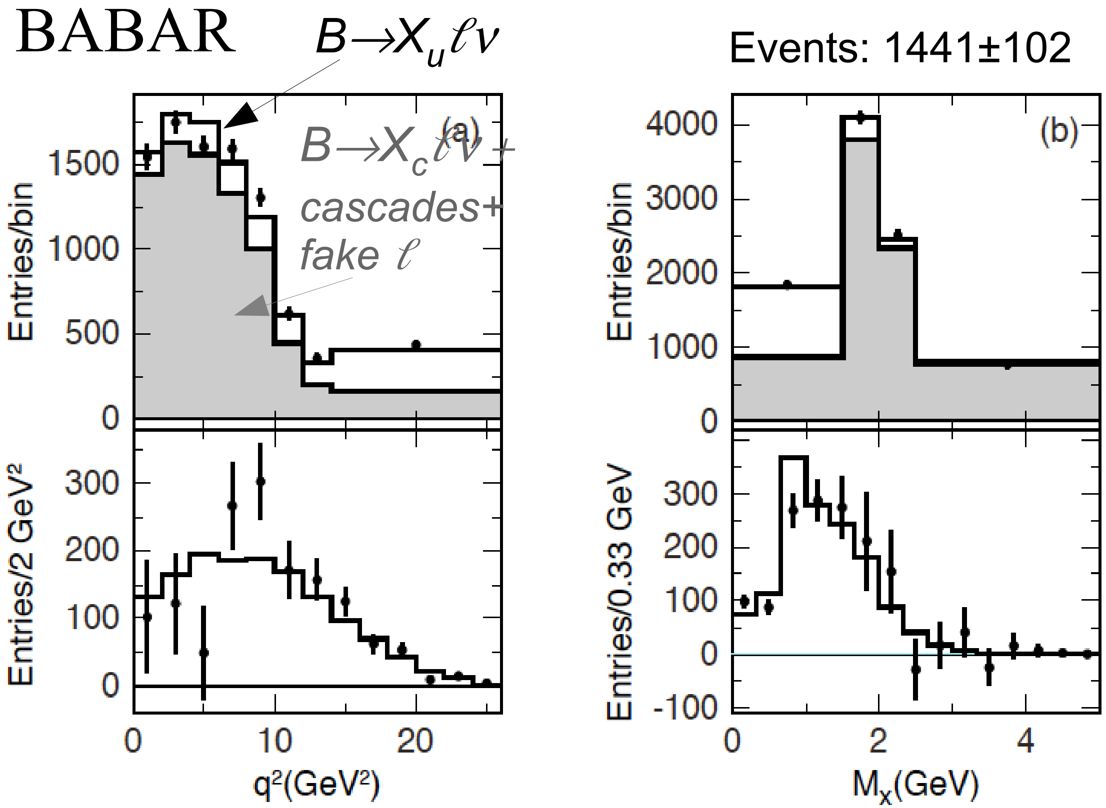


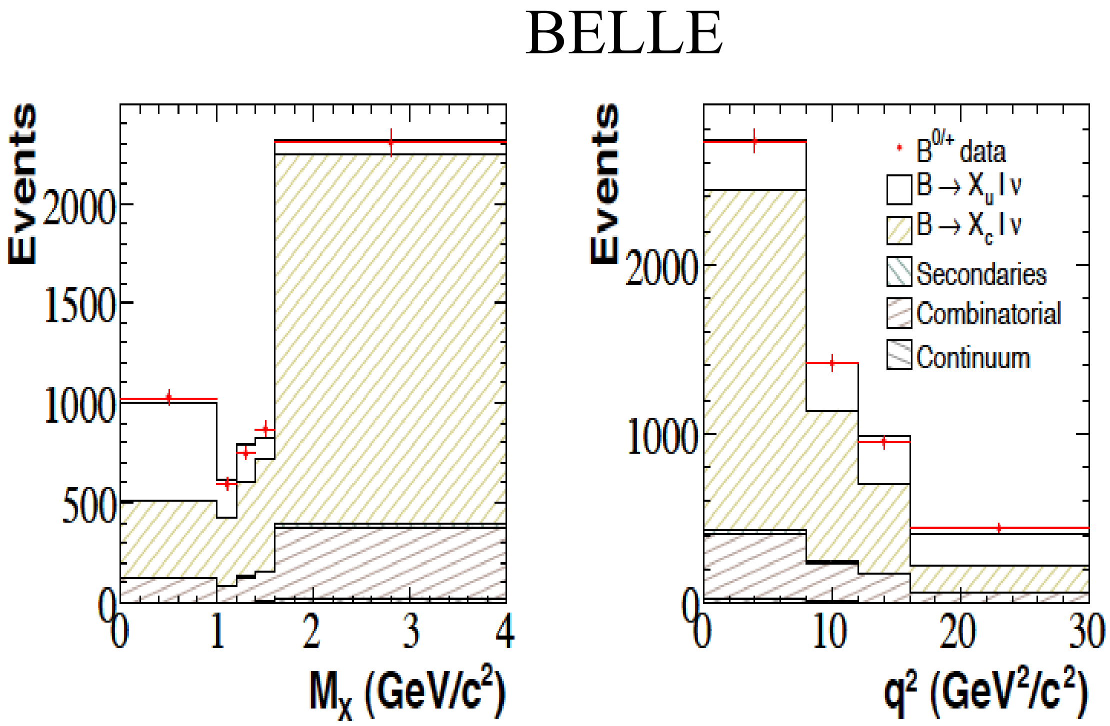
$$\frac{\Delta B(X_u \ell \nu)}{B(X \ell \nu)} = \frac{N_{b\to u}}{N_{X\ell\nu}} \cdot \frac{F}{\epsilon_{sel}}$$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\overline{B} \to X_u \ell \bar{\nu})}{\tau_B \, \Delta\Gamma_{\text{theory}}}}$$

Phase space Region	***GGOU x10³***
$M_X \leq 1.55$ GeV	$4.08 \pm 0.15 \pm 0.11^{+0.20}_{-0.21}$
$M_X \leq 1.70$ GeV	$3.94 \pm 0.17 \pm 0.14^{+0.16}_{-0.17}$
$P_+ \leq 0.66$ GeV	$3.75 \pm 0.17 \pm 0.15^{+0.30}_{-0.32}$
$M_X \leq 1.70$ GeV, $q^2 \geq 8$ GeV^2	$4.17 \pm 0.18 \pm 0.12^{+0.22}_{-0.25}$
$M_X - q^2$, $p^*_\ell > 1.0$ GeV	$4.35 \pm 0.16 \pm 0.18^{+0.09}_{-0.10}$
$p^*_\ell > 1.0$ GeV	$4.36 \pm 0.19 \pm 0.23^{+0.09}_{-0.10}$
$p^*_\ell > 1.3$ GeV	$4.33 \pm 0.18 \pm 0.20^{+0.10}_{-0.11}$

$|V_{ub}|$ From 2-dim q^2-M_x (P_ℓ>1 GeV) 88% of PS





	BaBar $|V_{ub}| \cdot 10^3$	Belle $|V_{ub}| \cdot 10^3$
BLNP	$4.28 \pm 0.24_{exp.} \pm 0.20_{th.}$	$4.47 \pm 0.27_{exp.} \pm 0.21_{th.}$
DGE	$4.40 \pm 0.24_{exp.} \pm 0.13_{th.}$	$4.60 \pm 0.27_{exp.} \pm 0.13_{th.}$
GGOU	$4.35 \pm 0.24_{exp.} \pm 0.10_{th.}$	$4.54 \pm 0.27_{exp.} \pm 0.11_{th.}$
ADFR	$4.29 \pm 0.24_{exp.} \pm 0.19_{th.}$	$4.48 \pm 0.30_{exp.} \pm 0.19_{th.}$

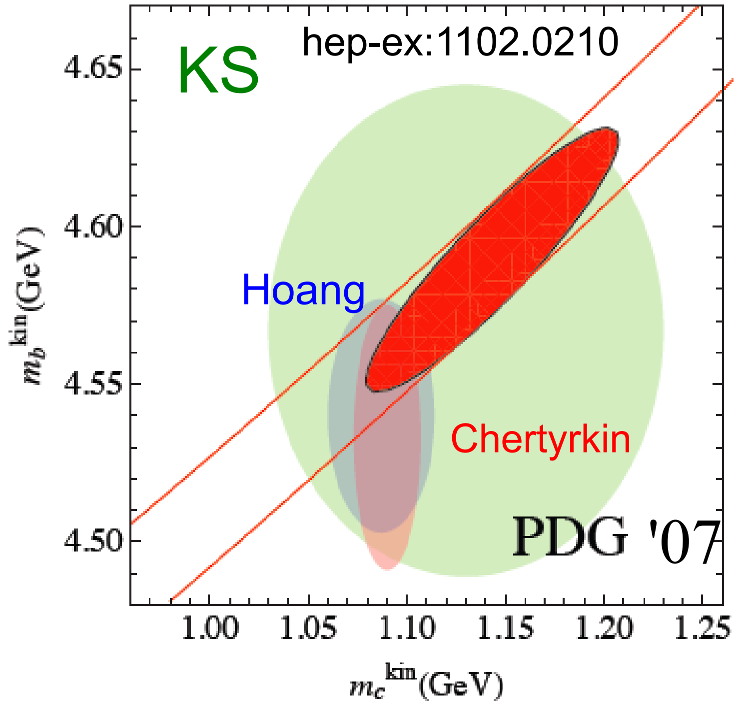
HQE parameters m_b, μ_π^2 rescaled to Global Fit results with m_c constraint (HFAG)

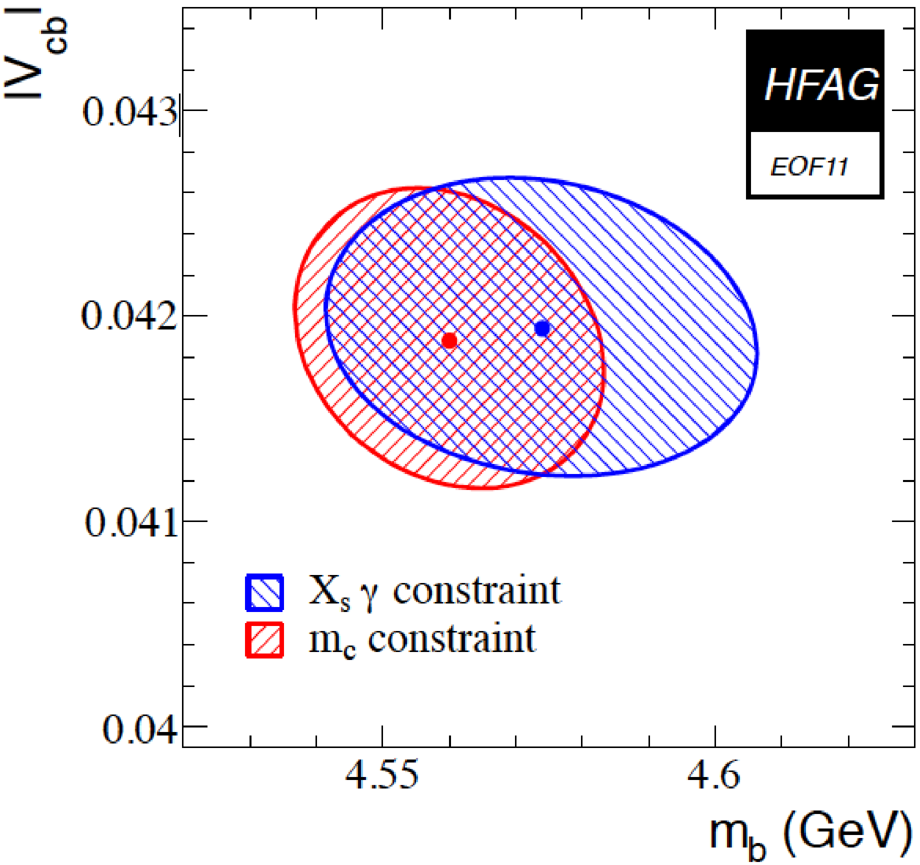
Next

Most important experimental syst is the signal model/composition

b-quark mass

- *Global Fit to 64 moments, determines precisely combination of m_b and m_c*
  - *Use also the precise m_c in MS scheme: $m_c(3GeV)=0.998(29)GeV$ arXiv:1102.2264*



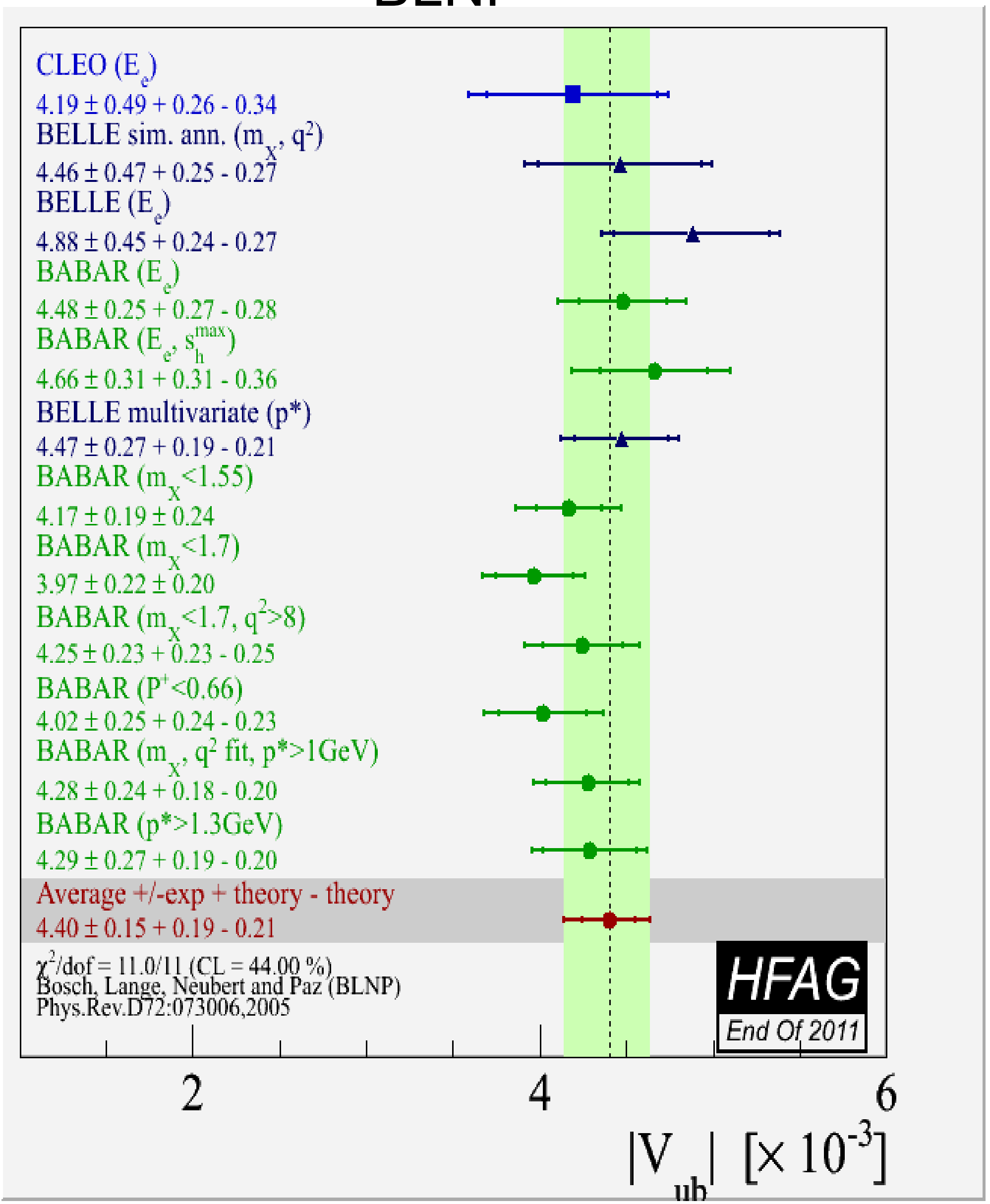


Constraint	$\|V_{cb}\|$ (10^{-3})	m_b^{kin} (GeV)	mu^2_{pi} (GeV^2)
Xsgamma	41.94 +/- 0.43(fit) +/- 0.59(th)	4.574 +/- 0.032	0.459 +/- 0.037
mc(3 GeV)	41.88 +/- 0.44(fit) +/- 0.59(th)	4.560 +/- 0.023	0.453 +/- 0.036

- *Higher order QCD terms (α_s^2 and m_b^3)*
- *m_c mass error could be reduced by ½*
- *Treatment of Correlations?*

Systematics

BLNP



Total Error: +5.6% -5.9%

Experimental error on the partial BF
Analysis with p_{lep} > 1 GeV (2-dim fit)

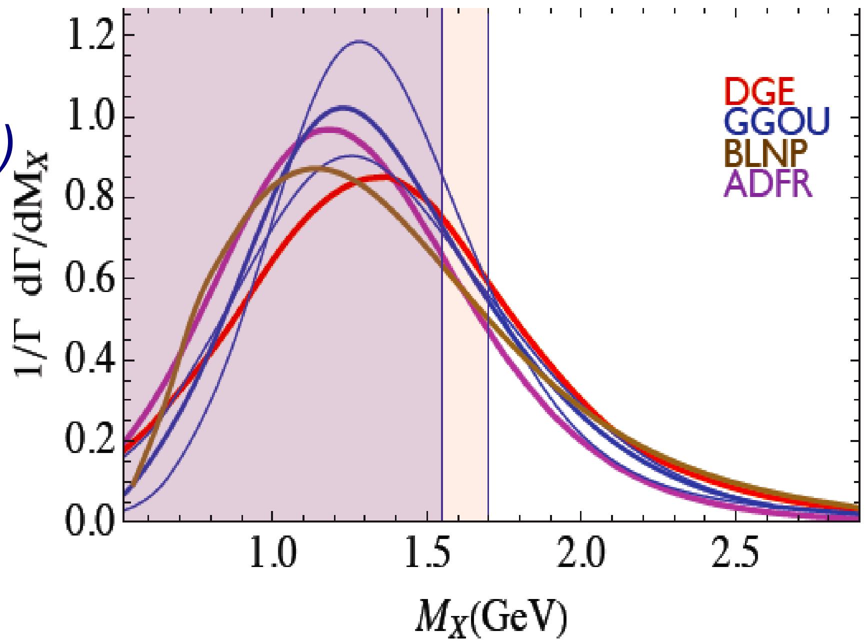
	BaBar%	Belle%
Detector	3.4	3.7
B->Xu	6.5	6.2
B->Xc & D	2.7	1.8
Fit	2.2	3.1
Stat	7.1	8.8

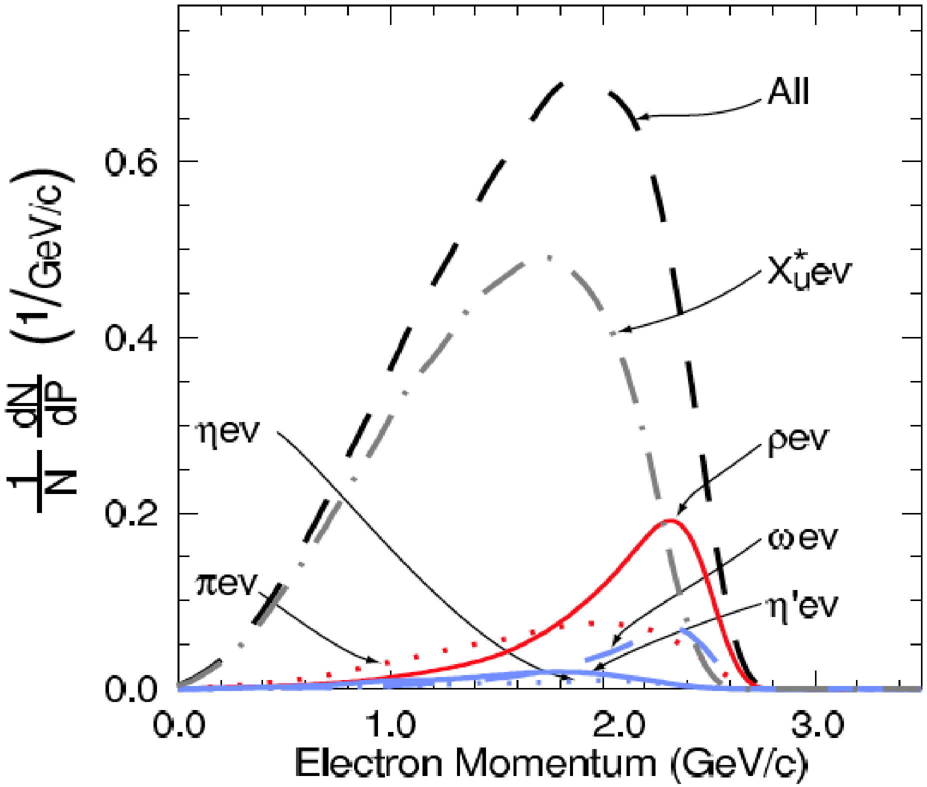
Theoretical uncertainty on the WA BLNP

	+σ%	-σ%
HQE model	+2.3	-2.4
SF function	+0.3	-0.3
Sub SF	+0.5	-0.7
WA	+0.0	-1.7
Matching	+3.7	-3.7

Inclusive: uncertainties

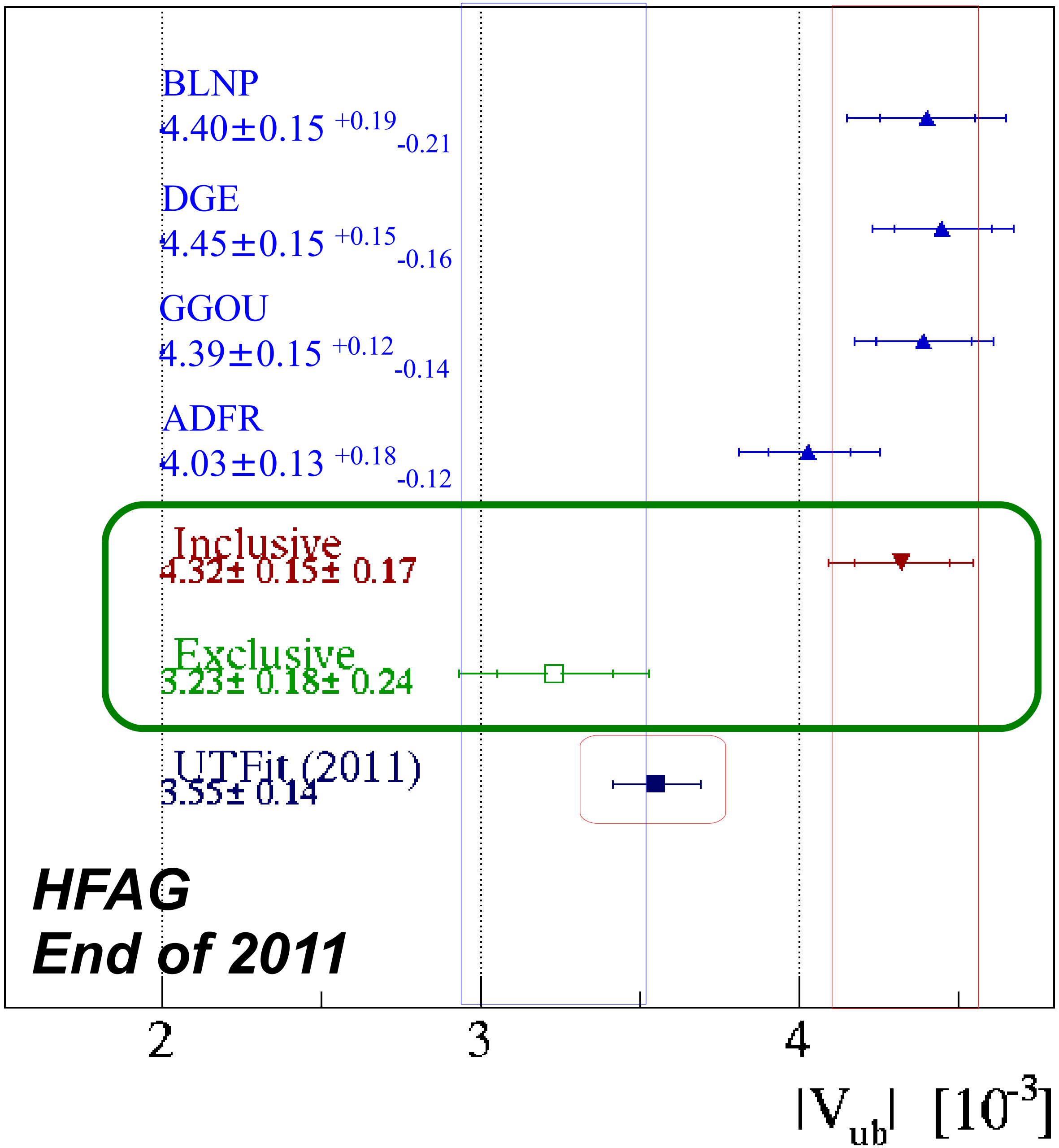
- *Uncertainties dominated by theoretical error*
  - *Recent calculation at NNLO (plugged in BLNP) increase $|V_{ub}|$ by 7%!*
  - *Test frameworks studying spectra!*
  - *Ongoing work on SIMBA ($|V_{ub}|$ global fit)*





- *Detector effects not relevant*
- *Dominant experimental systematic is due to the signal model*
  - *Resonant and not-resonant contribution*
  - *Important systematics for both inclusive and exclusive determination of $|V_{ub}|$*

Inclusive-Exclusive Discrepancy



Exclusive

$|V_{ub}| = (3.23 \pm 0.18_{exp.} \pm 0.24_{th.})\cdot 10^{-3}$

Inclusive

$|V_{ub}| = (4.32 \pm 0.15_{exp.} \pm 0.17_{th.})\cdot 10^{-3}$

Arithmetic average of the 4 inclusive determinations

$\Delta = 2.7\sigma$

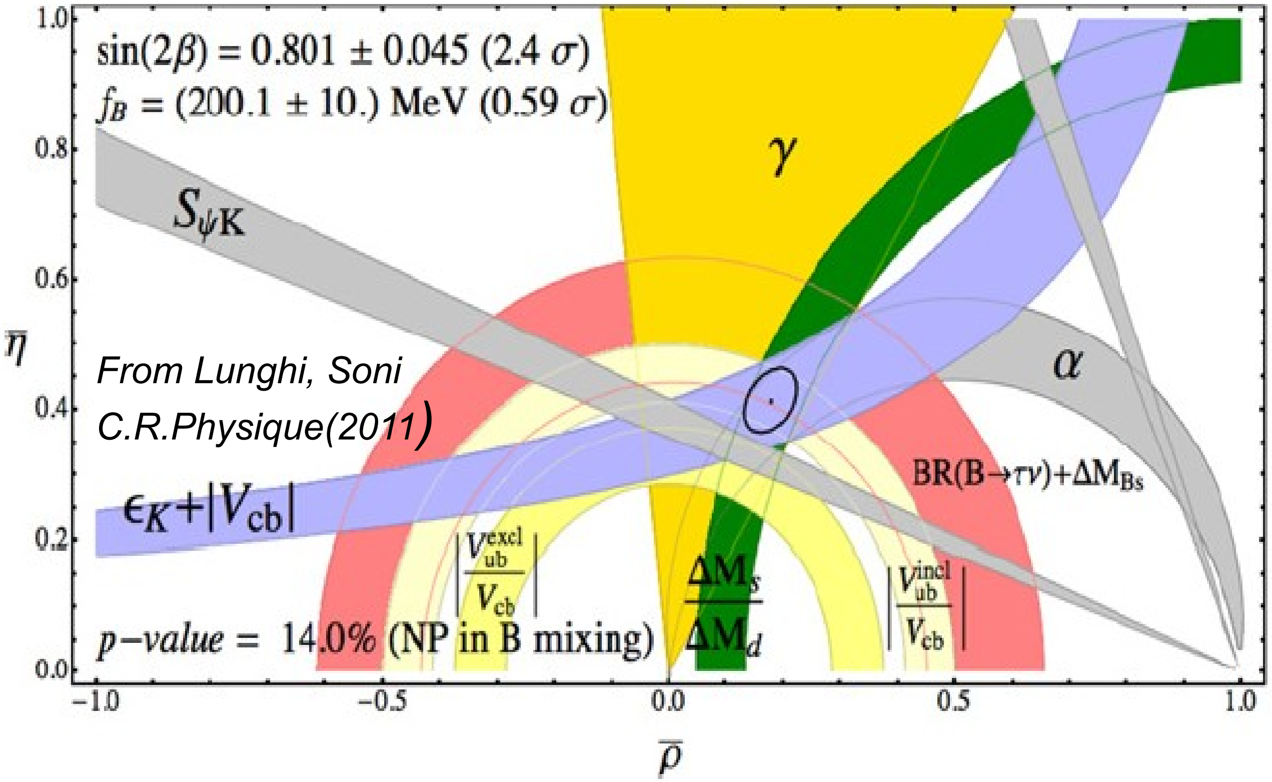
$B \to \tau\nu$

$|V_{ub}| = (5.0 \pm 0.6)\cdot 10^{-3}$

Based on BF average of 4 low statistics BF Measurements. Need more data!

Conclusions

- *Despite progresses from BFactories, the inclusive-exclusive discrepancy still present: 2.0-3.0σ differencies*
- *Crucial impact on UT constraints*



Will stay with us for a long time!?
Do we understand the QCD at (few)% level?
New Physics in the b->u transitions?

SuperB

- tagged sample: cleaner
- full understanding of the background composition / dynamics
- precise measurements of spectra

BUT:
Exclusive: Progress in QCD calculations, LQCD and LCSR
Inclusive: Require advanced QCD calculation and precise m_b

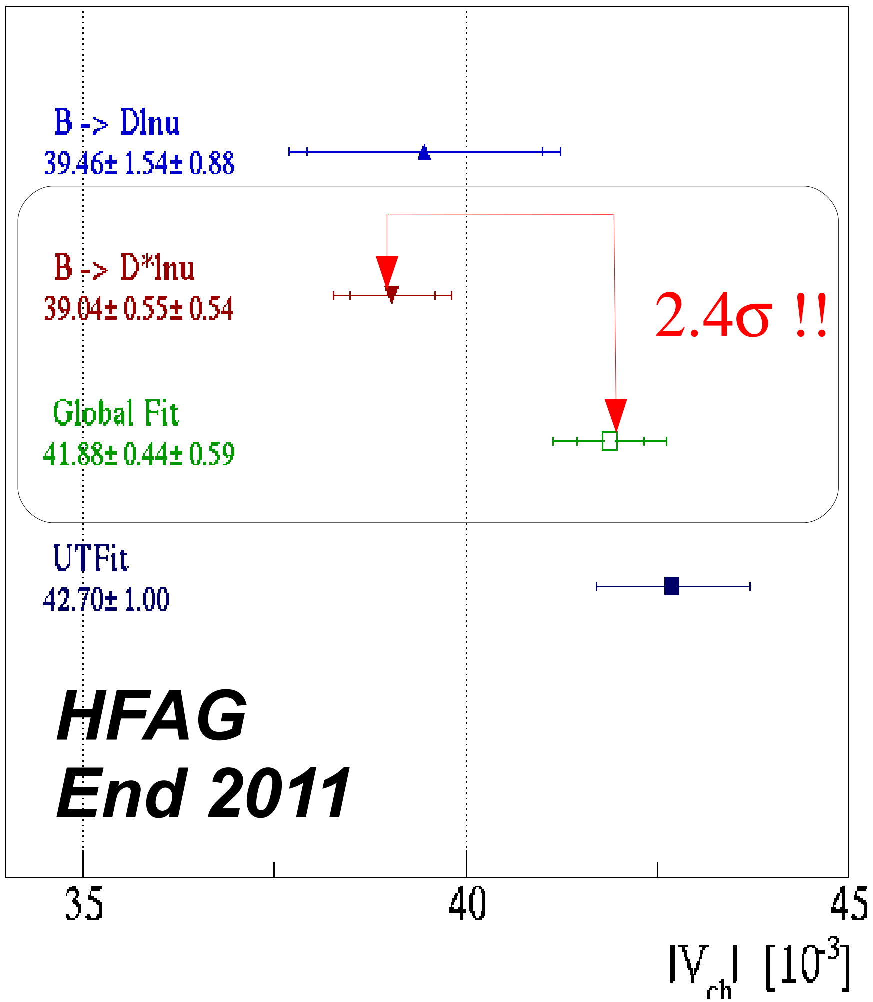
Comments

- *B-Factory era: untagged measurements give best measurements*
  - *Very high efficiency*
  - ***But large background due combinatorics from other B and from $B \to X_u \ell\nu$ bakground, very similar to the signal***
- *SuperB: will use mainly tagging (B_{reco} and SL)*
  - *Small efficiency*
  - ***Possible to apply loose cuts (es: low momentum cut)***
  - ***Reduce model dependence and overall systematics***

- *To improve the high q^2 region for untagged measurements is crucial to:*
  - *Understand the dynamics and composition of the $B \to X_u \ell\nu$*
- *Improvements expected from Lattice (<5% error ?)*

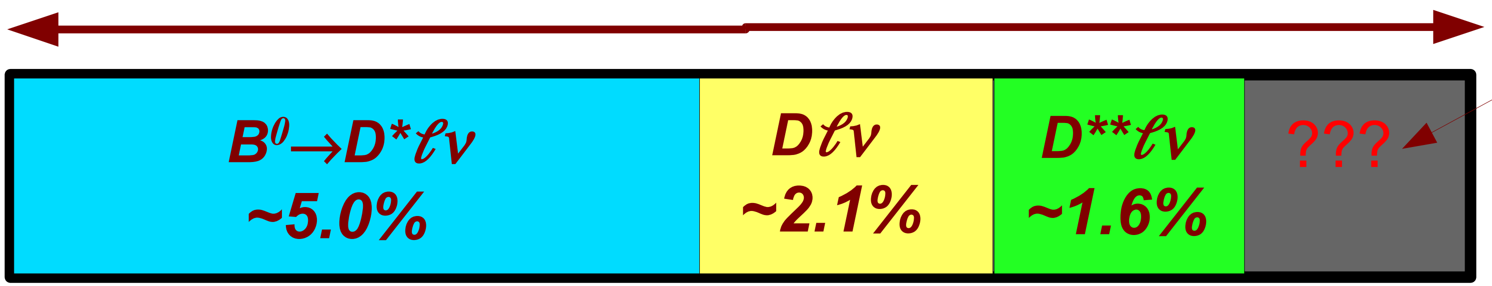
Issues with $|V_{cb}|$

- *Inclusive-Exclusive discrepancy*
  - *$B\to D\ell\nu$ is a useful cross checks: but compatible with both, improvements expected in the near future*
  - *Error on Inclusive is reliable and it's expected to decrease*
  - *Exclusive F(1) ?*
  - *Calculation based on HQ sum rules result in an increase of $|V_{cb}|$ (5%)*



- *Inclusive-Exclusive saturation problem:*

$Br(B^0\to X_c\ell\nu)=10.14 \pm 0.14$ %



Δ=1.6 ± 0.5 %

- *3 body decay of the D***
- *Multipion emission?*
- *Other resonances?*

Summary

- *Great improvements in the last decade*
  - *Many puzzles in SL decays still present and are now more important!*
  - ***Will stay with us for a long time !?***
  - ***Do we understand the QCD corrections at few % level?***

- *Improve the SL knowledge, for both $|V_{cb}|$ and $|V_{ub}|$*
  - *Reduce systematics due to background signal and background composition*
  - *Fix the gap of the missing exclusive decays*
- *Use the large B_{reco} sample available:*
  - *Expect 5000/fb^{-1} of tagged B meson!*

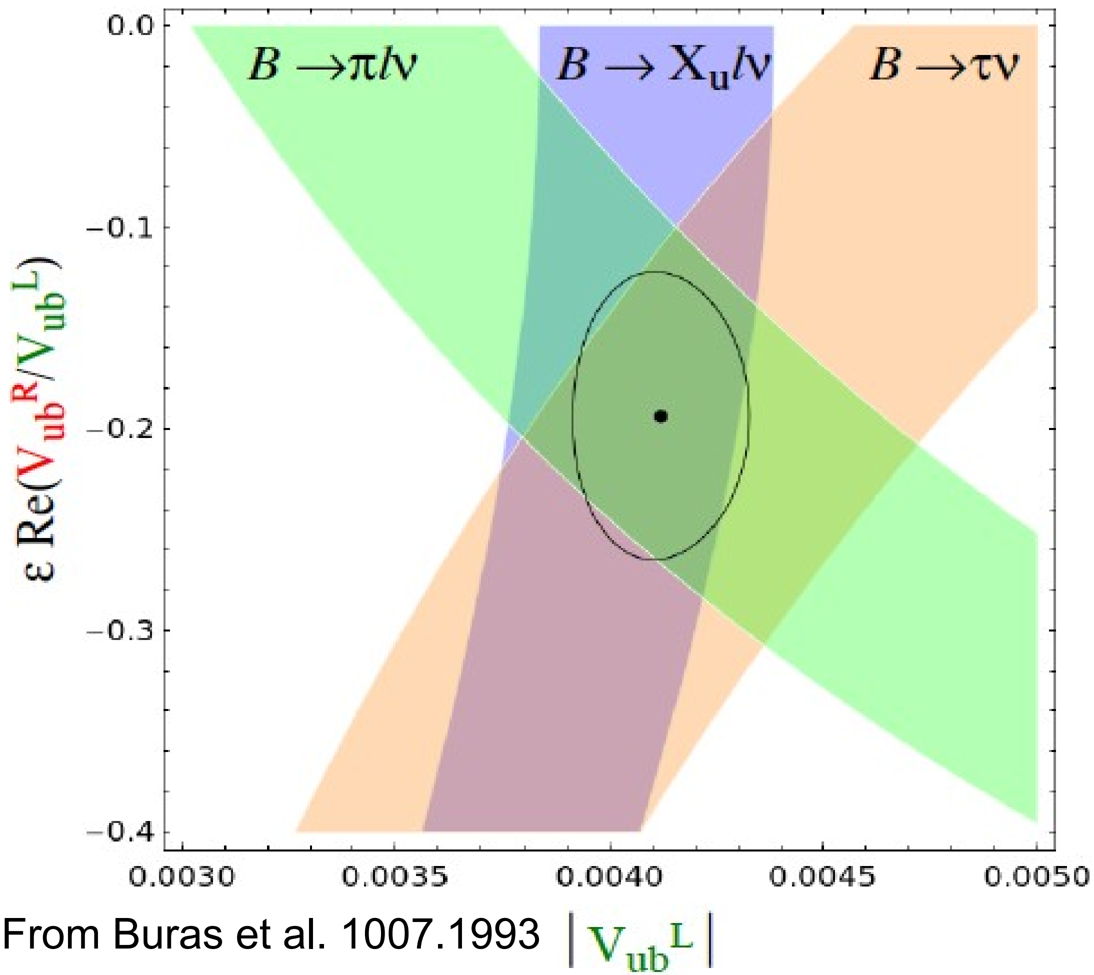
Puzzle solution: New Physics ?

- *The Right-Handed currents could explain the differencies:*

$$V_{ub} u_L\ W\ b_L \quad \Longrightarrow \quad V_{ub}(u_L\ W\ b_L + \xi^R_{ub} \cdot u_R\ W\ b_R)$$

Chen, Nam
Buras, Gemmler
Lunghi, Soni

- *Impact SL and Leptonic decays*



From Buras et al. 1007.1993

$$|V_{ub}|_{\rm incl} \Longrightarrow \sqrt{1+|\xi^R_{ub}|^2}|V_{ub}|_{\rm incl}$$

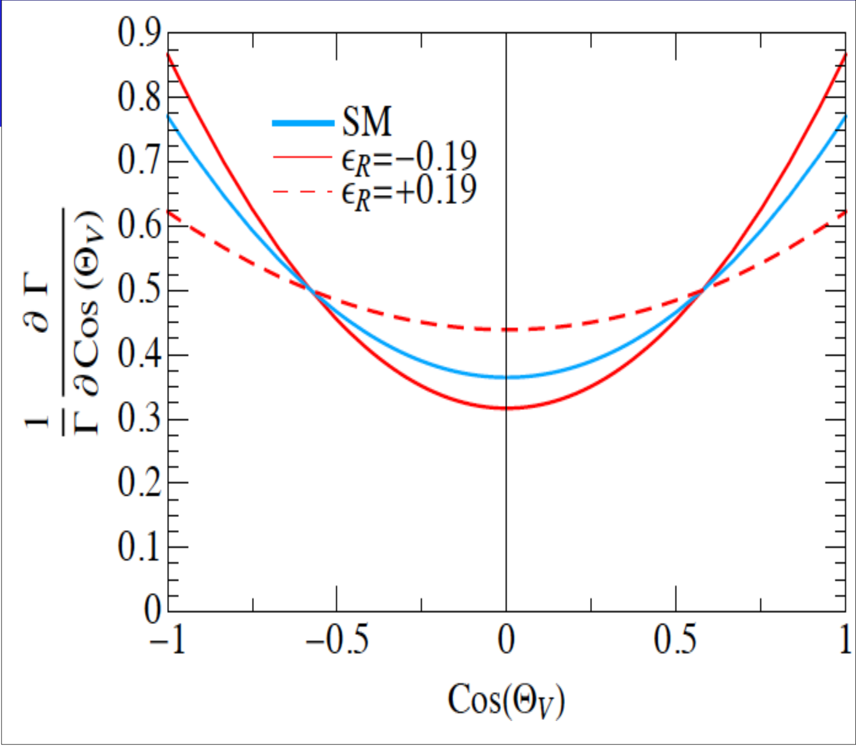
$$|V_{ub}|_{\rm excl} \Longrightarrow |1+\xi^R_{ub}|\ |V_{ub}|_{\rm excl}$$

$$\mathrm{BR}(B\to\tau\nu) \Longrightarrow |1-\xi^R_{ub}|^2\mathrm{BR}(B\to\tau\nu)$$

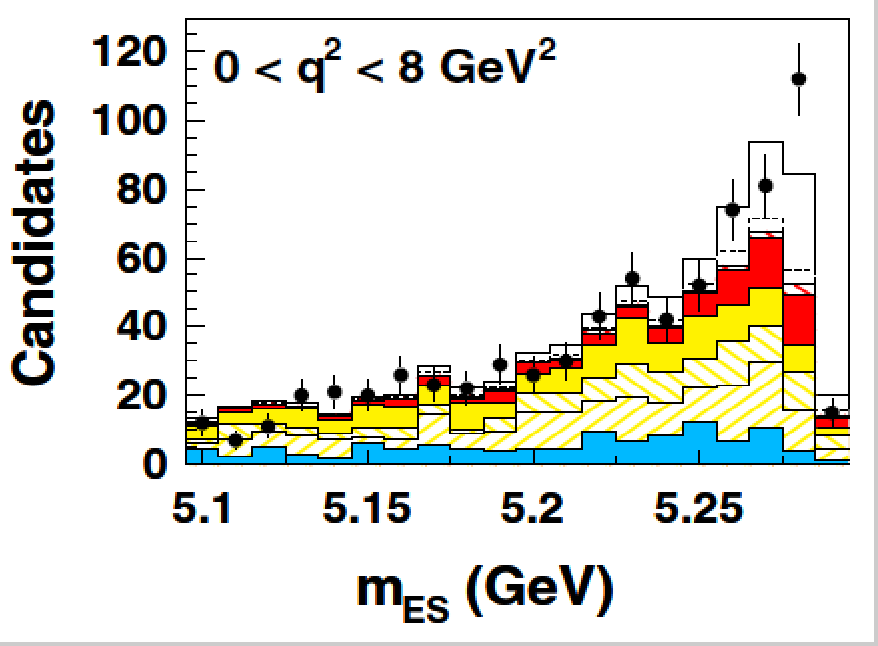
- *Large RH contribution is required (~20%)*
- *An RH current does not significantly contradict existing observables*
- *Need to study specific observables*
  - $B\to\rho\ell\nu$ ...

$B \to \rho \ell \nu$

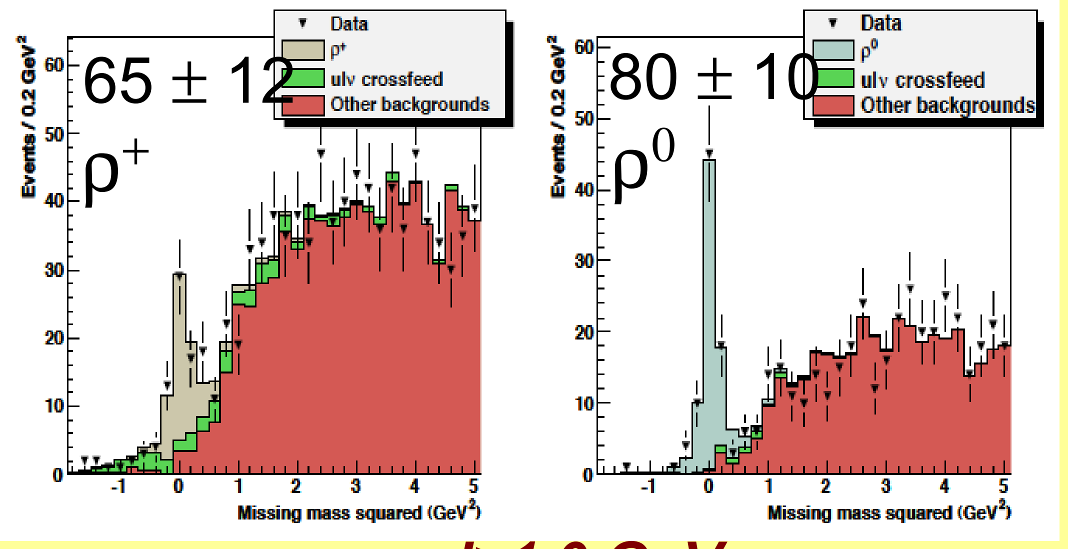
- $B \to \rho \ell \nu$: non trivial test of V-A, V+A contribution
- ρ helicity distribution: affected by phase space
  - Require high statistics and good precision!



Untagged is affected by large bkg:
- need tight cuts: ***pl>2.0 GeV***
- BaBar 350fb-1:
3300 ± 290 events with S/N~0.1



B_{reco} with 670 fb-1 (Belle)



pl>1.0 GeV

Approach $|V_{ub}|$ differently ?

- *Use MORE rare decays, very clean:*

$$\frac{\mathrm{d}\Gamma(\bar{B}_d \to \rho\ell\nu)/\mathrm{d}q^2}{\mathrm{d}\Gamma(\bar{B}_d \to K^*\ell^+\ell^-)/\mathrm{d}q^2} = \frac{|V_{ub}|^2}{|V_{ts}V_{tb}|^2} \cdot \frac{8\pi^2}{\alpha^2} \cdot \frac{1}{N(q^2)} \cdot R_B$$

  - *R_B from 'Grinstein double ratio':*

$$\frac{f^{(B\to\rho\ell\bar{\nu})}}{f^{(B\to K^*\ell^+\ell^-)}} \times \frac{f^{(D\to K^*\ell\bar{\nu})}}{f^{(D\to\rho\ell\bar{\nu})}}$$

- *Use EVEN more Rare Decays, even more clean:*

$$\frac{\frac{\Gamma(B_u\to\tau\nu)}{\Gamma(B_s\to\ell^+\ell^-)}}{\frac{\Gamma(D_d\to\ell\nu)}{\Gamma(D_s\to\ell\nu)}} \sim \frac{|V_{ub}|^2}{|V_{ts}V_{tb}|^2} \cdot \frac{\pi^2}{\alpha^2} \cdot \left(\frac{f_B/f_{B_s}}{f_D/f_{D_s}}\right)^2$$