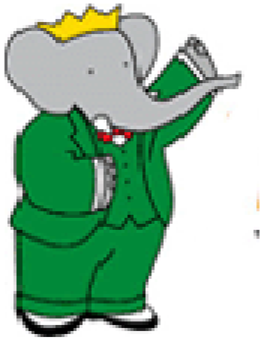
CKM Matrix Elements from B−Factories



Martino Margoni

Universita‘ di Padova & INFN

(on behalf of the BaBar Collaboration)

Outlook:

➔ V_{cb}:

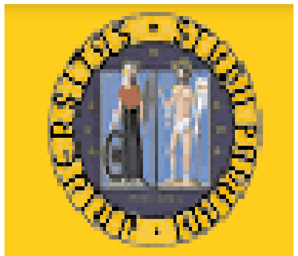
Inclusive & Exclusive Semileptonic $B \to X_c l\nu$ Decays

➔ V_{ub}:

Inclusive & Exclusive Charmless Semileptonic B Decays

➔ V_{td}, V_{ts}:

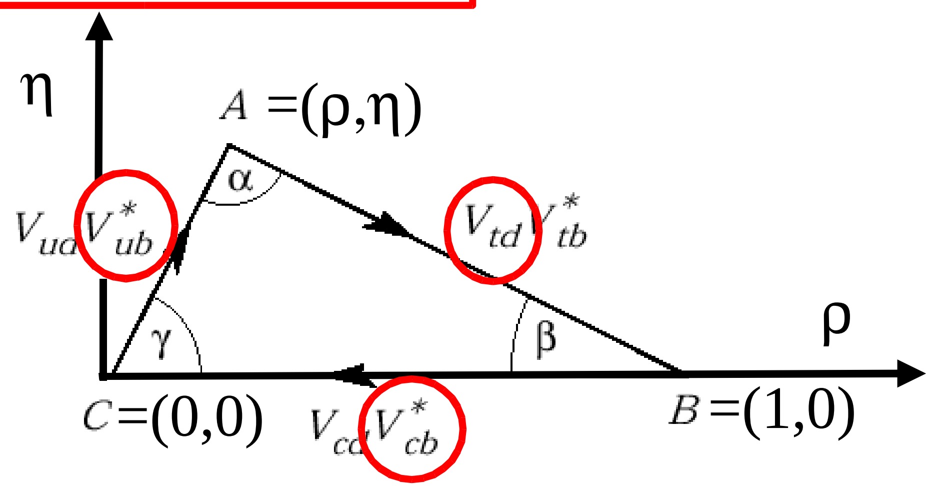
B^0 Mixing, Radiative Penguin, $B^+ \to \tau^+\nu_\tau$



CKM Matrix Elements Measurements

➔CKM quark Mixing Matrix (Wolfenstein parameterization):

$$V=\begin{pmatrix} V_{ud} & V_{us} & \boxed{V_{ub}} \\ V_{cd} & V_{cs} & \boxed{V_{cb}} \\ \boxed{V_{td}} & \boxed{V_{ts}} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & \boxed{A\lambda^3(\rho-i\eta)} \\ -\lambda & 1-\lambda^2/2 & \boxed{A\lambda^2} \\ \boxed{A\lambda^3(1-\rho-i\eta)} & \boxed{-A\lambda^2} & 1 \end{pmatrix}$$



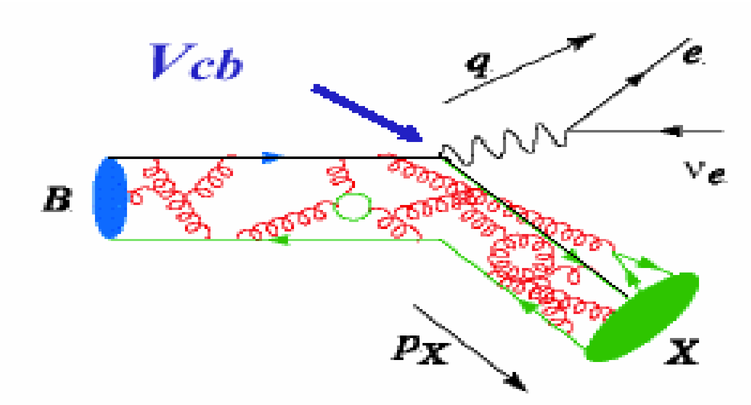
➔Unitarity condition:

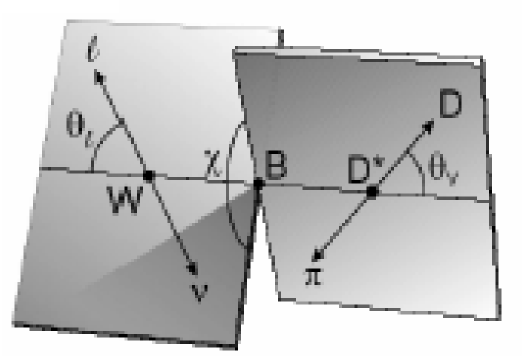
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

➔V_{ub}, V_{cb}, V_{td} , V_{ts} Measurements constraint sides of unitarity triangle

➔Directly probe CPV mechanism via complex phase iη

V_{cb} Measurements





Inclusive Measurements VS Exclusive Measurements

$$\Gamma_{sl}(b\to c l\nu)=\gamma_b |V_{cb}|^2=\frac{BR(b\to c l\nu)}{\tau_b}$$

➔HQE ($1/m_b$, α_s) to deal with QCD perturbative + non−perturbative (not calculable) interactions

➔Experimentally: measure moments of kinematic variables (E_l, M_X) & $BR(b\to X_c l\nu)$

➔Major issue: unfold the true shapes from the measured ones

➔V_{cb} from the measured differential rate of $B\to D^{(*)}l\nu$ + OPE

$$\frac{d\Gamma}{dw}\propto G(w)F(w)^2|V_{cb}|^2,\ w=\vec{v}_B\cdot\vec{v}_D$$

➔Probe different FF parameterizations & QCD bounds

V_{cb} Inclusive Measurements: Theory

➔ V_{cb} from total b → c SL width: $\Gamma(B\to X_c l\nu)=\frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2(1+\delta_{ew})A_{pert}A_{non-pert}$

➔ Non perturbative parameters cannot be calculated, need to be measured

➔ Heavy Quark Expansion:

prediction of inclusive spectral moments in B rest frame as a function of the minimum lepton energy E_{cut} in terms of non−perturbative parameters a_i:

$$M^{l(X)}_n = f_{OPE}(m_b, m_c, a_i)$$

➔ Electron Energy moments

$$M^l_0(E_{cut})=\frac{\int_{Ecut}^{\infty} d\Gamma}{\Gamma_B} \quad \text{(Partial BR)}$$

$$M^l_1(E_{cut})=\langle E_l\rangle_{El>Ecut}$$

$$M^l_n(E_{cut})=\langle (E_l - M^l_1(E_{cut}))^n\rangle_{El>Ecut}$$

Hadronic Mass moments

$$M^X_n(E_{cut})=\langle m^n_X\rangle_{El>Ecut}$$

➔ Strategy:
Measure moments to get non−perturbative parameters

V_{cb} Inclusive Measurements: Strategy

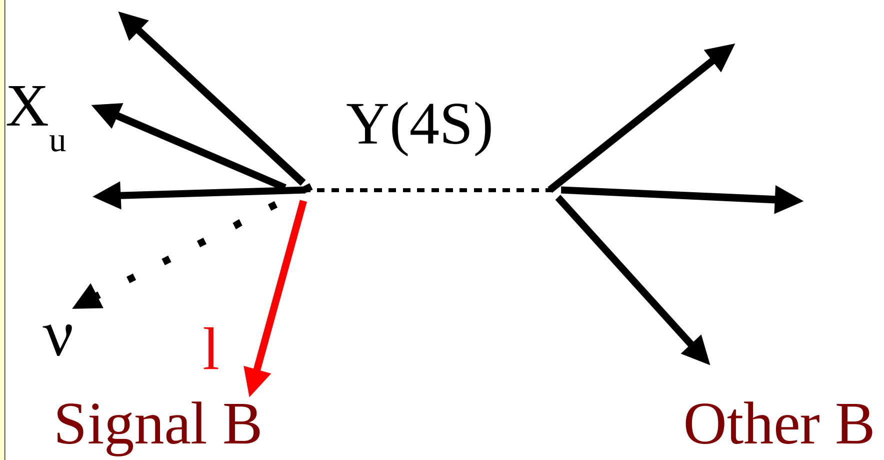
STUDY

Inclusive variables:

➔ $BR(b \to X_c l\nu)$

➔ Lepton energy spectrum (better experimental precision)

➔ Hadronic mass spectrum (more sensitive to non−perturbative terms)



USING

➔ Recoil of Fully Reconstructed $B \to D^{(*)}X$ (clean environment, small sample)

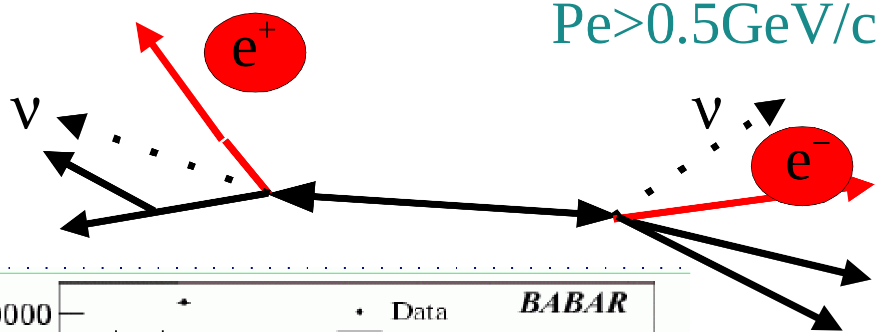
➔ High momentum lepton (high efficiency)

➔ V_{cb} & non−perturbative parameters from a global fit to several distributions

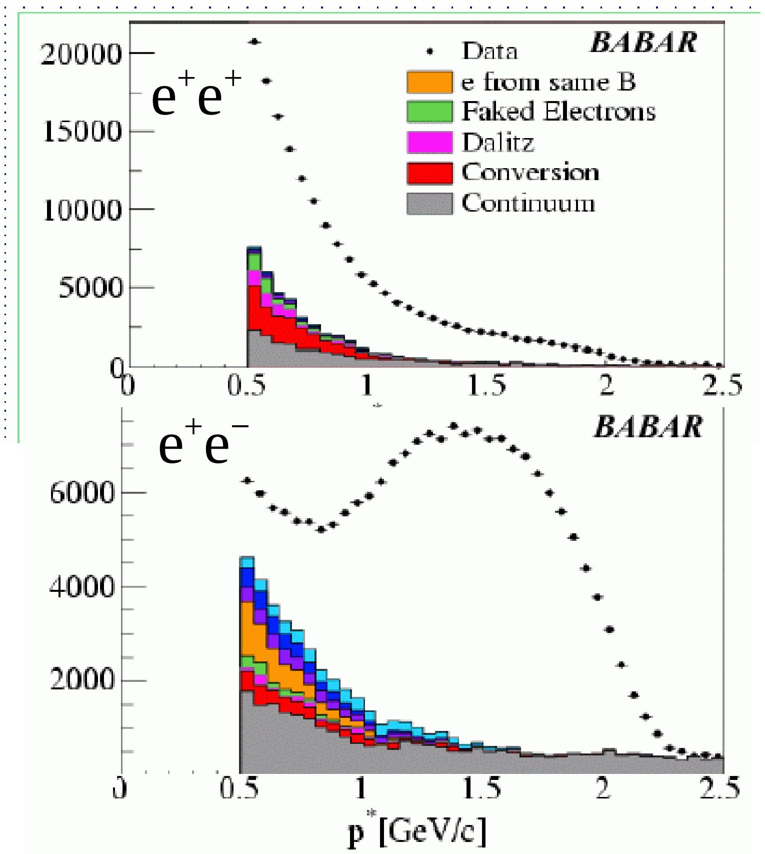
BaBar E_e Spectrum & BR($b \to X_c l\nu$) (47 fb^{-1})

Btag:
Pe>1.4GeV/c

Bsig:
Opposite charge
Pe>0.5GeV/c



- ➔Suppress electrons from same B by cut on angle between the 2 e
- ➔J/Ψ veto
- ➔Continuum described by off−peak events
- ➔γ conversions, Dalitz, fakes from control samples
- ➔Spectrum unfolding for detector Bremmsstrahlung & FSR



➔Ecut=0.6GeV: [hep−ex 0403030]

BR($b \to X_c l\nu$) = (10.36±0.06±0.23)%

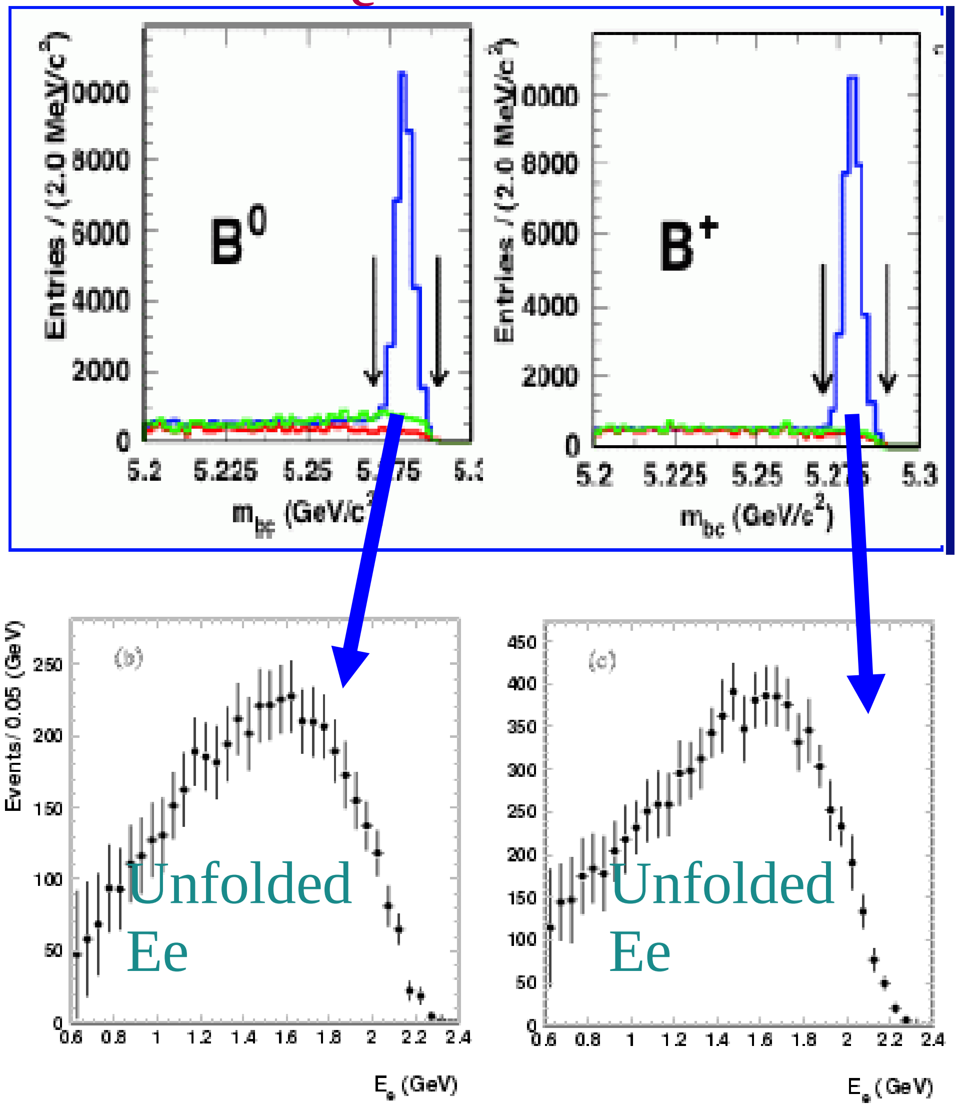
M_1=1432.8±3.9±7.8MeV

$M_2 \times 10^3$=148.0±2.2±3.1GeV^2

$M_3 \times 10^3$=−12.05±0.88±0.46GeV^3

➔Systematics from e−identification, upper vertex charm

Belle E_e Spectrum & BR($b \to X_c l\nu$) (140 fb^{-1})



➔ $B^{0(+)} \to D^{(*)}X$ fully reconstructed in several modes

➔ Bsig: P_e >0.6GeV/c

➔ J/Ψ, Dalitz, γ conversion veto, cascade subtraction

➔ B^0 sample: mixing correction

➔ $B \to X_u l\nu$ subtraction after spectrum unfolding (detector, QED)

➔ Ecut=0.6GeV:
[hep−ex/0411066; hep−ex/0409015]

BR($b \to X_c l\nu$) = (10.34±0.20±0.36)%

BR^+/BR^0= 1.08±0.05±0.02

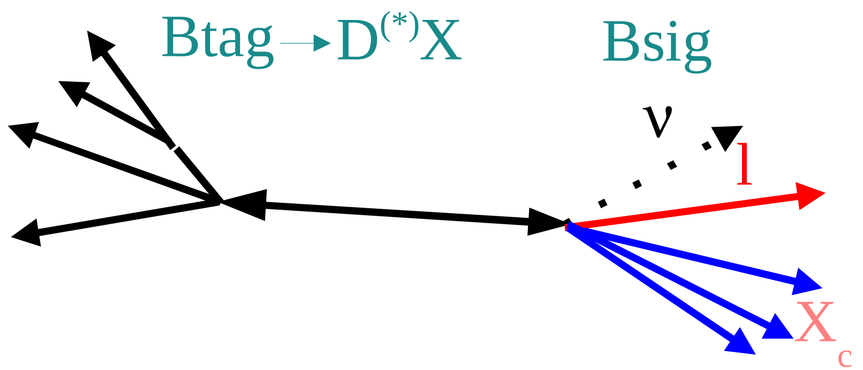
$M_1(B^0)$=1444.9±5.5±2.8MeV

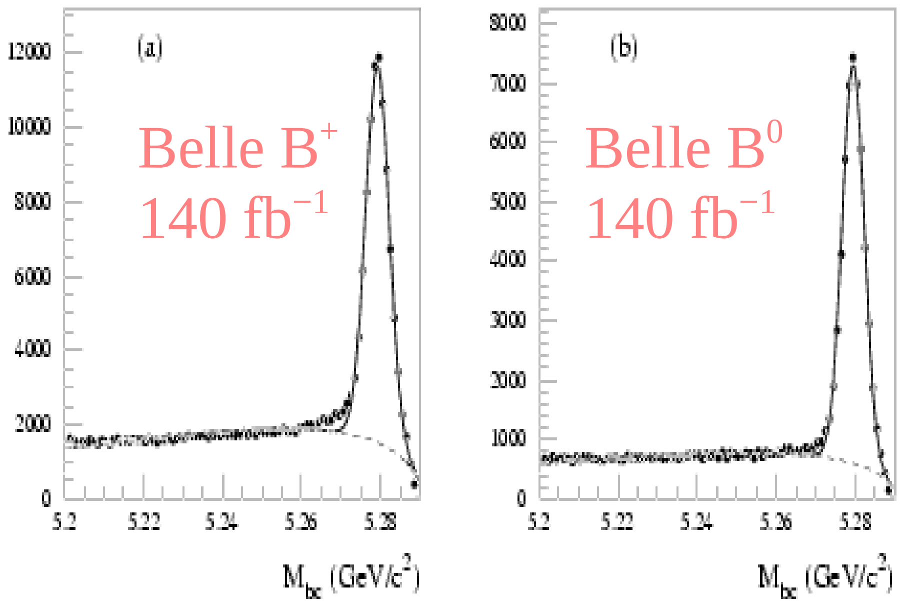
$M_1(B^+)$=1432.1±4.3±3.6MeV

➔ B^0 vs B^+ measurements: probe non−spectator effects

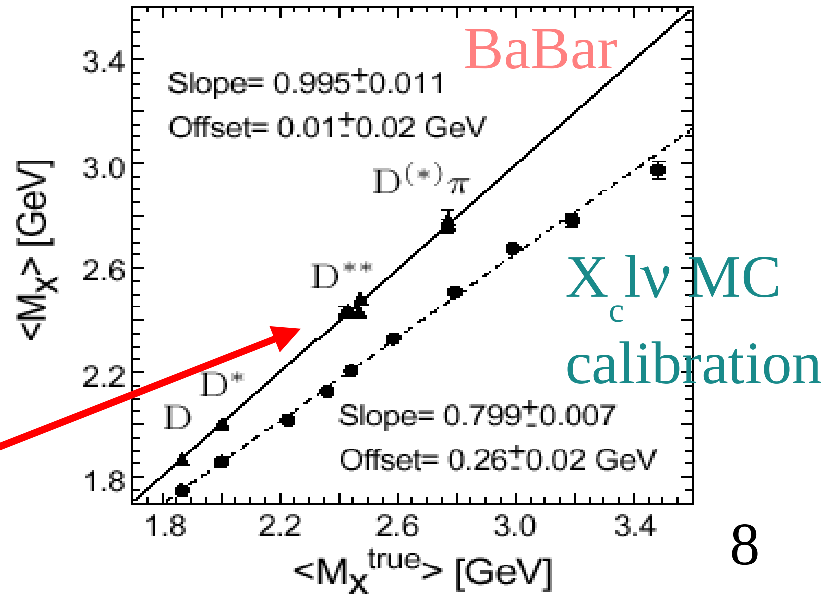
➔ Systematics from PID & cascade

Hadronic Mass Spectrum Analyses



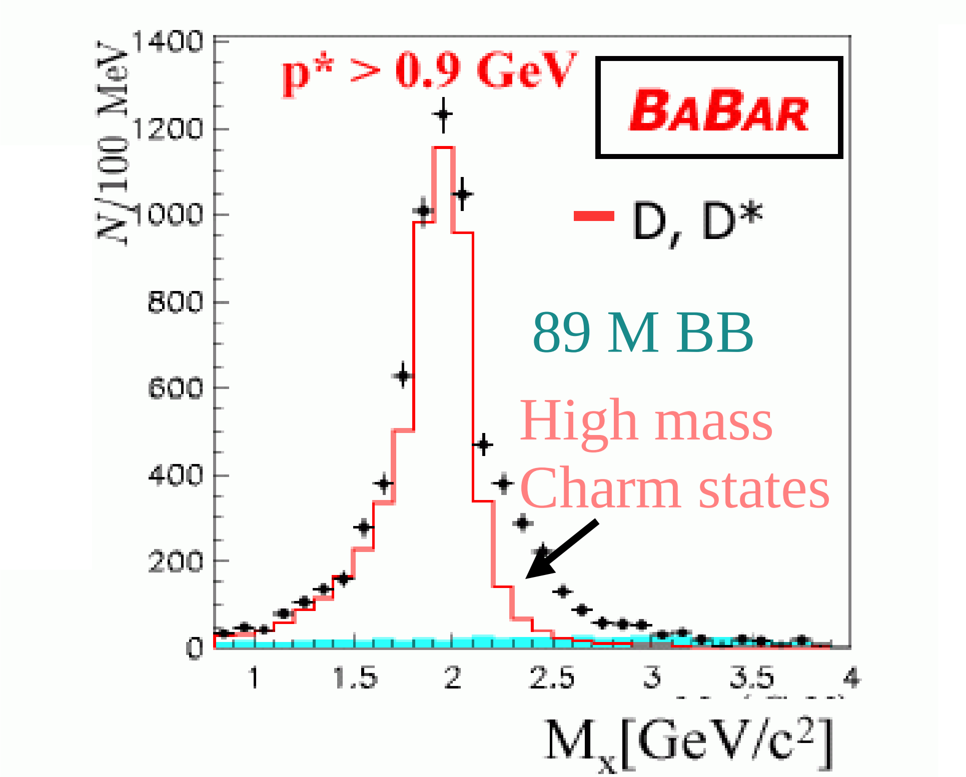


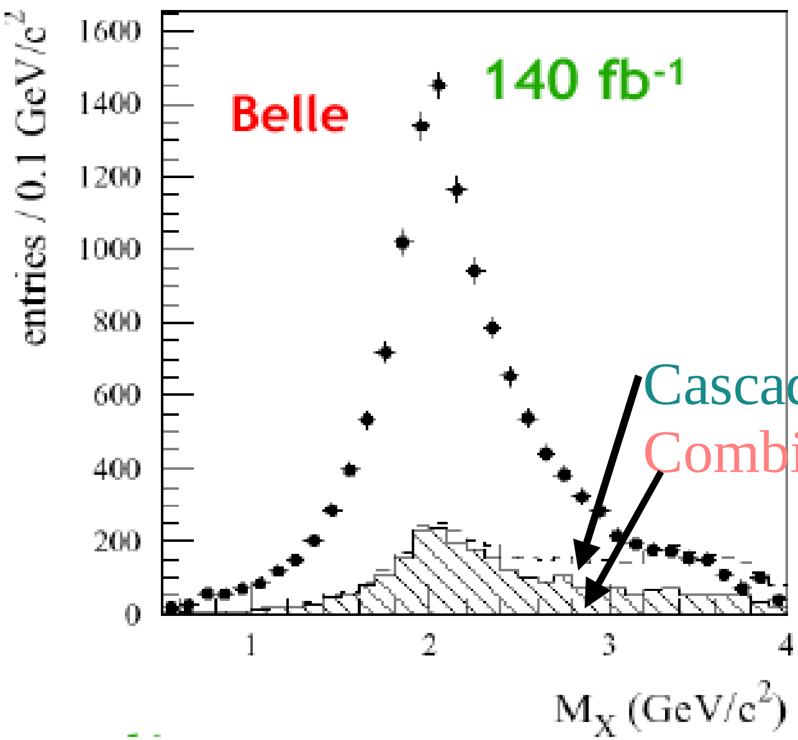
- ➔Fully reconstructed Btag→$D^{(*)}X$
- ➔Bsig: look for e/μ with P>0.9GeV/c
- ➔Pmiss, Emiss consistent with ν
- ➔M_X from a constrained kinematic fit (σM_X~200−350 MeV/c^2)
- ➔Combinatorial BKG from MC & M_{ES} side band, continuum from off−peak events



➔M_X spectrum correction (detector, QED) from MC, validate on exclusive final states

Hadronic Mass Spectrum Analyses





➔Fit relative contributions of D, D^*

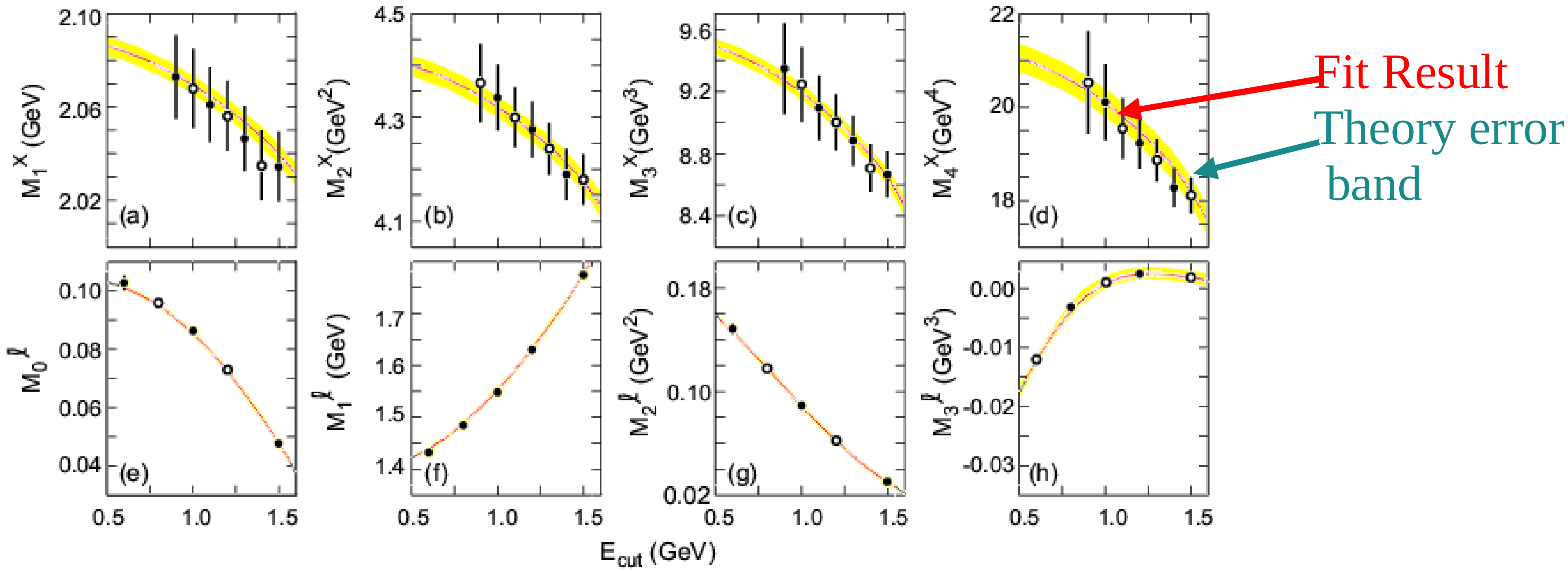
➔Ecut=0.9GeV:

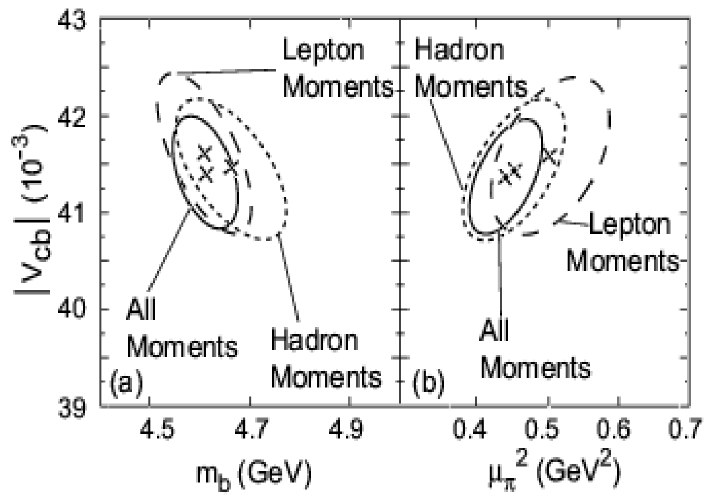
M^X_1=2.073±0.013±0.013GeV/c	2.076±0.009±0.010GeV/c
M^X_2=4.366±0.049±0.058GeV^2/c^4	4.334±0.046±0.051GeV^2/c^4
[BaBar: hep−ex/0403031]	[Belle: hep−ex/0408139]

➔Systematics: efficiency, combinatorial & cascade BKG, modeling hadronic states in MC, unfolding

HQE Fits to Hadronic & Leptonic Moments

➔BaBar HQE Fit (Gambino, Uraltsev) kinetic scheme: 8 free parameters





➔$V_{cb} \times 10^3 = 41.4 \pm 0.4_{exp} \pm 0.4_{HQE} \pm 0.6_{(\alpha s,\Gamma)}$

➔$BR(b \to X_c l\nu) = (10.61 \pm 0.16_{exp} \pm 0.06_{HQE})\%$

[hep−ex/0404017]

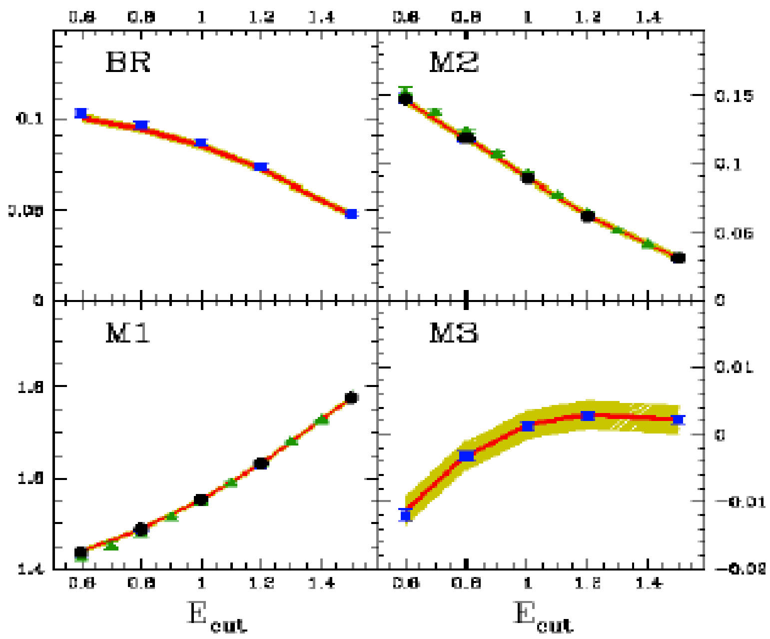
➔Separate fits to hadron & lepton moments give consistent results

V_{cb} Inclusive Measurements:Summary

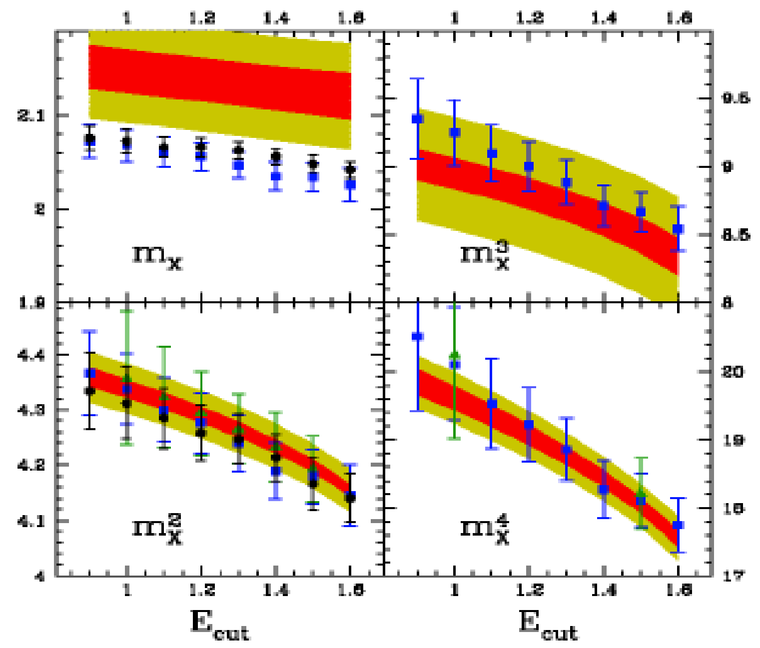
➔Global fit in m_b^{1S} scheme (BaBar, Belle, CLEO, CDF, DELPHI)

[Bauer, Ligeti, Luke, Manohar, Trott: Phys. Rev. D70 094017]

Leptonic moments



Hadronic Moments



➔$V_{cb}\times 10^3 = 41.4 \pm 0.6$; $m_b^{SF} = 4.68 \pm 0.03$ GeV

➔$\delta V_{cb} < 2\%$; m_b very precise: leading error on V_{ub}

➔Non perturbative corrections fixed at the $(\Lambda_{QCD}/m_b)^3$ level

➔Waiting for Belle own fit

V_{cb} Exclusive Measurements: Theory

➔ V_{cb} from differential decay width of $B^0 \to D^{(*)} l \nu$ decays:

$$\frac{d\Gamma}{dw} \propto \underbrace{G(w)}_{\text{Phase Space}} \underbrace{F(w)^2}_{\text{Form Factor}} |V_{cb}|^2, \quad w = \vec{v}_B \cdot \vec{v}_D$$

$$\mathcal{F}(w) = \mathcal{F}(1)\left[1 - \rho^2_{\mathcal{F}}(w-1) + c_{\mathcal{F}}(w-1)^2 + \cdots\right] \quad D$$

$$\left.\begin{aligned} \mathcal{F}_*(w) &= \mathcal{F}_*(1)\left[1 - \rho^2_{\mathcal{F}_*}(w-1) + c_{\mathcal{F}_*}(w-1)^2 + \cdots\right] \\ h_{A_1}(w) &= h_{A_1}(1) \cdot f(w \,|\, \rho^2_{A1}, \ldots) \end{aligned}\right\} D^*$$

➔ Different OPE FF parameterizations available

➔ $D^+ l\nu$: smaller theoretical error; experimentally more challenging

QCD Bounds:

➔ Normalization:

$F(1) = 1.04 \pm 0.01 \pm 0.01$; $h_A(1) \sim F^*(1) = 0.92 \pm 0.03$

➔ Curvature:

$c > 0$; $c_{F^*} \sim 0.66\, \rho^2_{F^*} - 0.11$

➔ Slope:

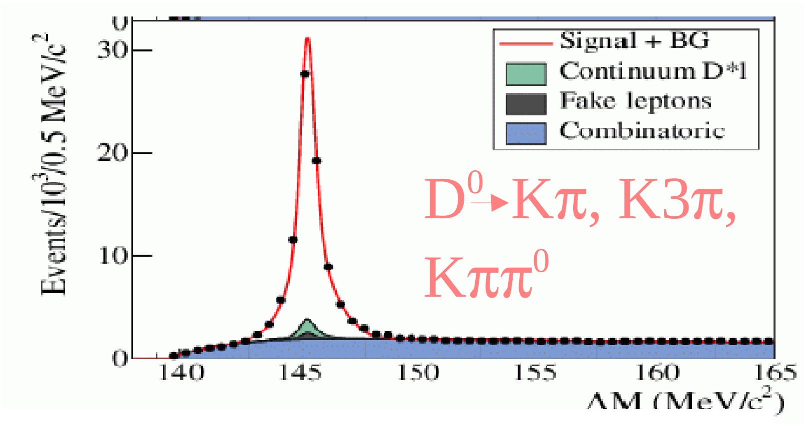
$3/4 < \rho^2_{F^*} < 1$; $\rho^2_F - \rho^2_{F^*} \sim 0.19$; $\rho^2_{A1} - \rho^2_{F^*} \sim 0.17$; $\rho^2_{A1} \sim \rho^2_{F^*}$

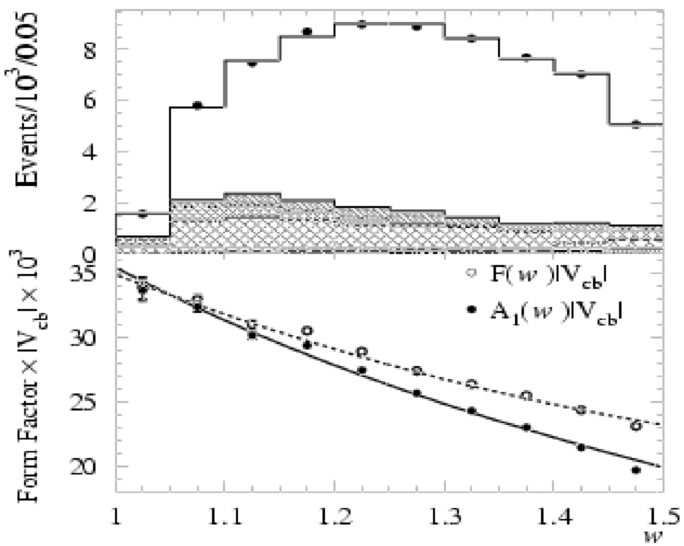
Experimentally:

➔ Determine $F^*(1)V_{cb}$, ρ^2 by $d\Gamma/dw$ fit using bounds

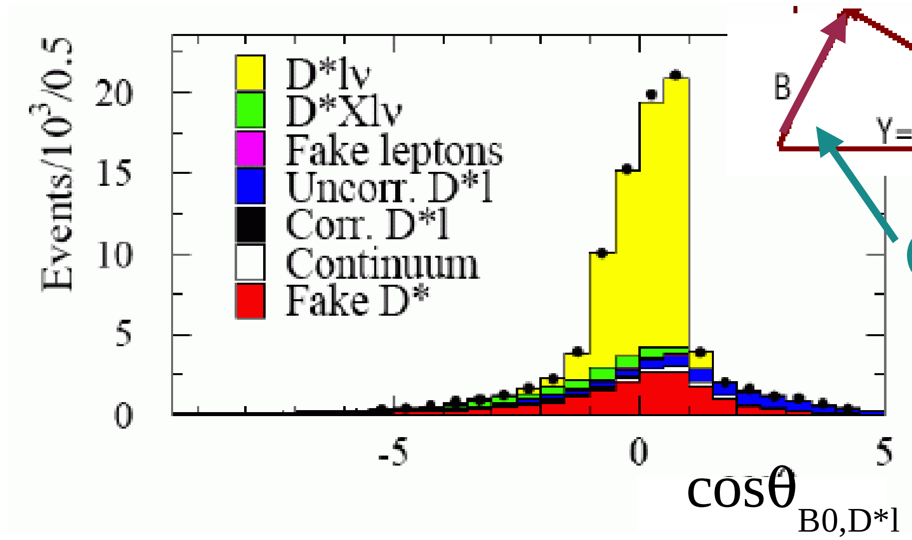
➔ Probe shape parameters by fit without constraints

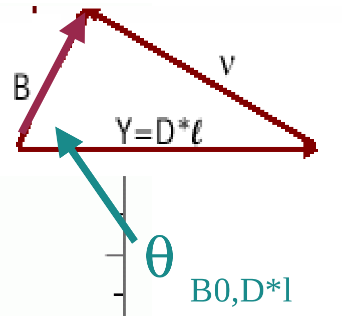
BaBar $B^0 \to D^* l \nu$ Analysis (80 fb^{-1})





	$\mathcal{A}_1(1)\|V_{cb}\| \times 10^3$	ρ^2	c	χ^2/ndf
$\mathcal{F}$	35.0 ± 0.9	0.95 ± 0.09	0.54 ± 0.17	67/57
$\mathcal{A}_1$	35.5 ± 0.8	1.29 ± 0.03	-	69/58





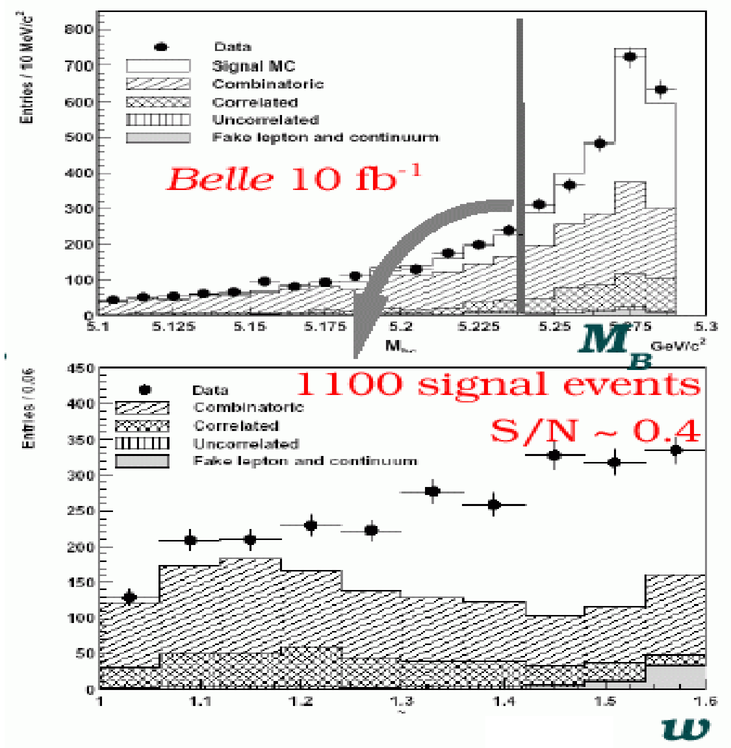
➔Sample composition from a fit to ΔM & $\cos\theta_{B0,D^*l}$ in each w bin ($\sigma(w)=0.04$)

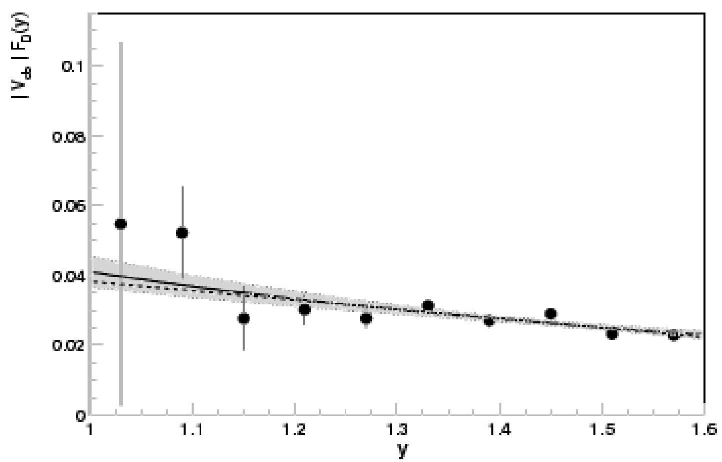
$V_{cb} \times 10^3 = 38.7 \pm 0.3_{stat} \pm 1.7_{syst} \pm 1.4_{theo}$
[PRD−RC 71, 051502]

➔Theoretical constraints satisfied

➔Systematics from $R_{1,2}$ (ratio Axial to Axial & Vector to Axial FF), D^0 BR, f_{00}, τ_{B0}

Belle $B^0 \to D^+ l\nu$ Analysis (10 fb^{-1})





➔ $D^+ \to K^-\pi^+\pi^+$, $P_l > 0.8 GeV/c$

➔ Main issue:
ν reconstruction from P_{miss}, E_{miss} to compute B mass (not needed in $D^* l\nu$ analysis)

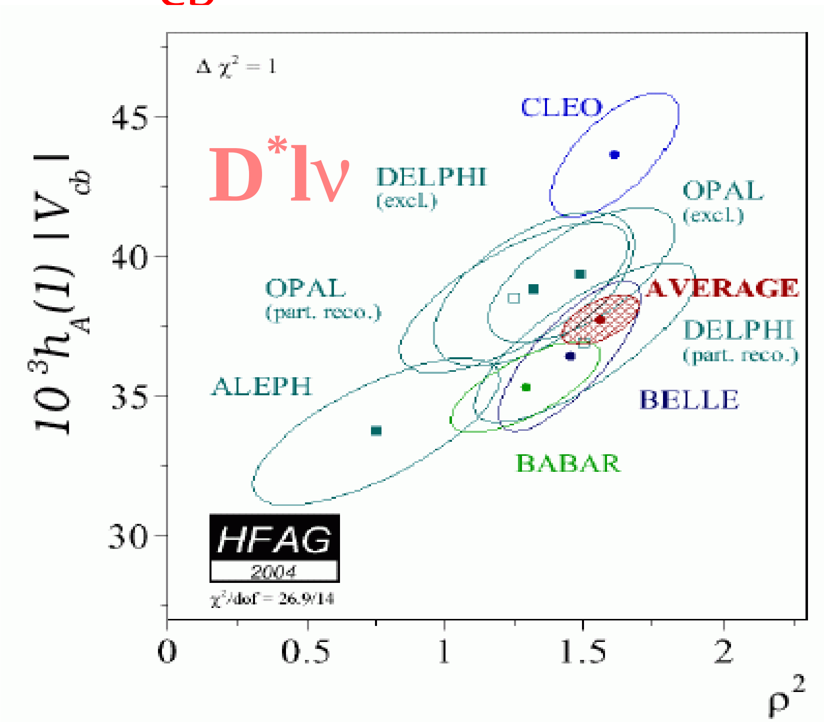
➔ Correlated BKG from $D^{*(**)} l\nu$

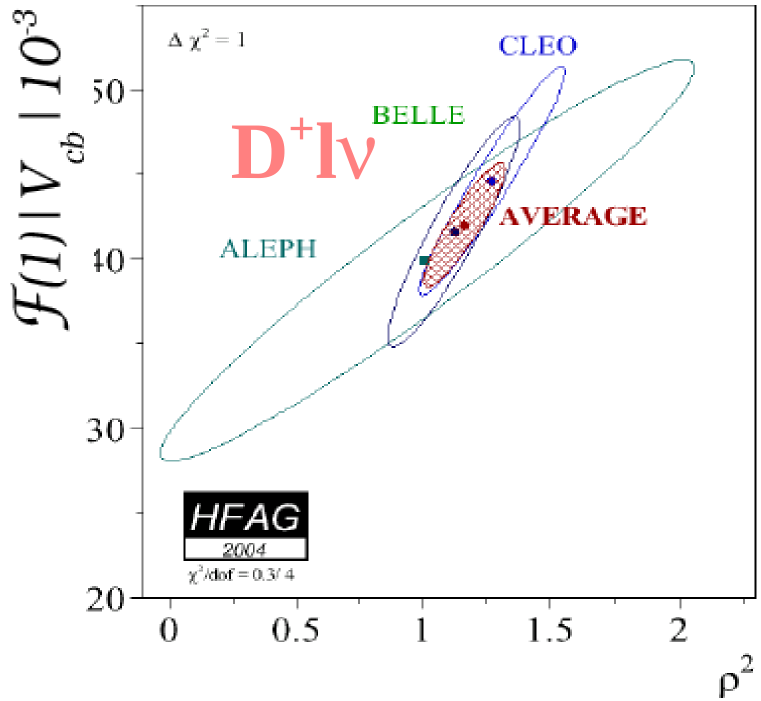
➔ Poor S/N

➔ $V_{cb} \times 10^3 = 41.9 \pm 4.5_{stat} \pm 5.3_{syst} \pm 3.0_{theo}$ [PLB 526, 258]

➔ Dominant Systematics from ν reconstruction, D^+ vertexing, D^+ BR, correlated BKG normalization

V_{cb} Exclusive Measurements:Summary





- ➔ $V_{cb} \times 10^3 = \quad 41.4 \pm 1.0_{exp} \pm 1.8_{theo}$
- ➔ Loose internal Consistency
- ➔ Experimental error will decrease
  $(\tau_{B0}$, D^0 BR, f_{00}, $R_{1,2})$

$39.1 \pm 3.6_{exp} \pm 1.3_{theo}$

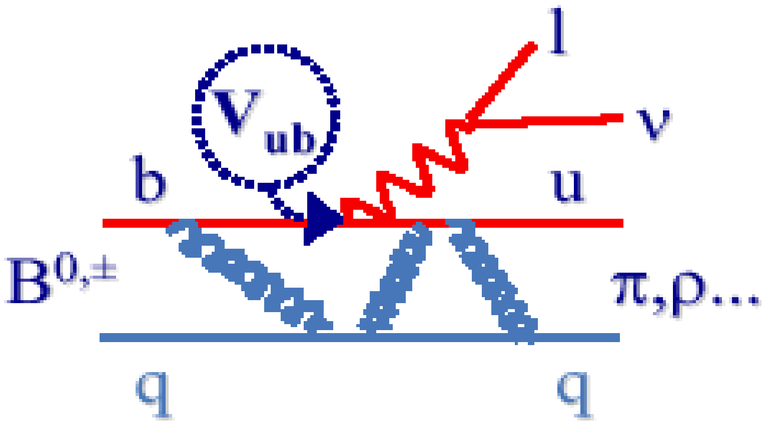
Good internal consistency

Need other methods (tagged samples)

Smaller theoretical error

V_{ub} Measurements

Charmless semileptonic B decays, $B \to X_u l\nu$



Experimentally Challenging

Very High $B \to X_c l\nu$ BKG

➔Tight selection cuts

➔Limited phase space

➔Extrapolation uncertainties

Inclusive Measurements VS Exclusive Measurements

Study inclusive kinematic quantities after charm suppression;

➔V_{ub} from total BR($b \to u l\nu$)

➔Major issue: Extrapolation to the full phase space (Shape Function)

Study exclusive decay channels;

➔V_{ub} from partial BR($B \to X_u l\nu$)

➔Major issue: QCD uncertainties in Form Factor prediction (non perturbative effects)

V_{ub} Inclusive Measurement: Theory

➔ V_{ub} from OPE, using charmless total semileptonic BR & τ_B:

$$|V_{ub}| = 0.00424 \left(\frac{BR(B \to X_u l \nu)}{0.002} \frac{1.61\, ps}{\tau_b} \right)^{1/2} \times \left(1.0 \pm 0.028_{OPE} \pm 0.039_{mb}\right)$$ ➔ 5% theoretical error

➔ ...But space phase is limited due to experimental cuts for charm BKG rejection

➔ Standard Approach (ICHEP04, HFAG): total BR from ΔBR:

$$BR(B \to X_u l \nu) = \frac{\Delta BR}{f_u(m_b, \Lambda^{SF}, \lambda_1^{SF})} (1 + \delta_{Final\ State\ Rad.})$$

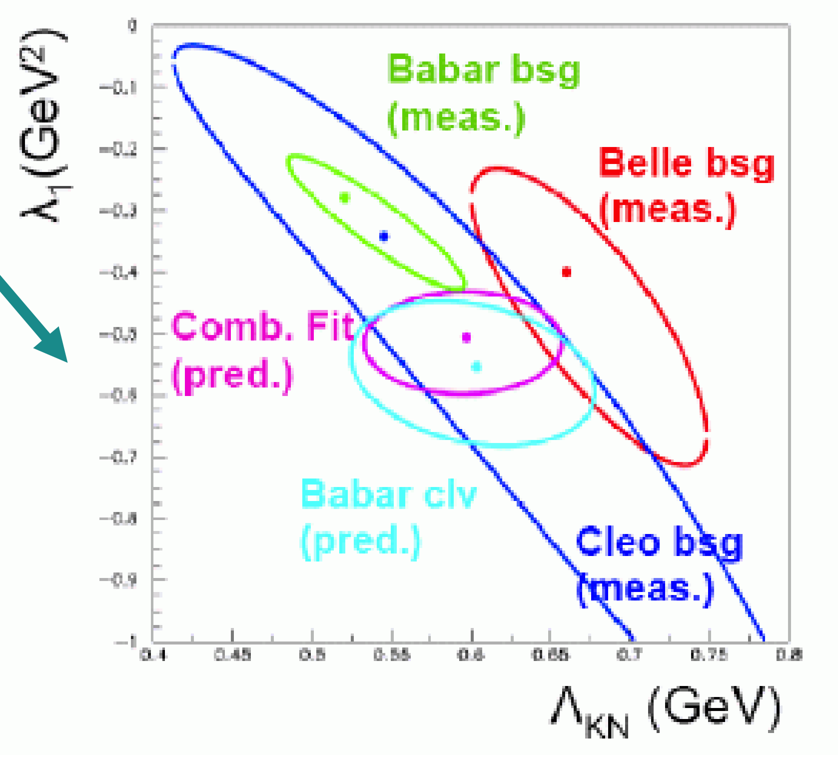
Kinematic Acceptance from differential decay rate (E_l, m_X, q^2) computed to $O(\alpha_s, 1/m_B^2)$ (de Fazio, Neubert)

Shape Function parameters from $b \to s\gamma$ spectrum (Belle)

V_{ub} Inclusive Measurement: Theory

➔ New Theoretical Approach (Bosch, Lange, Neubert, Paz): improved treatment of SF effects & weak annihilation estimation

➔ Kinematic Acceptances computed using Shape Function parameters from BELLE $b \to s\gamma$ spectrum & BaBar $b \to c l \nu$ hadronic & leptonic moments



➔ Theory error better defined

➔ V_{ub} directly from ΔBR:

$$|V_{ub}| = \sqrt{\frac{\Delta BR}{\tau_b \Delta \Gamma}}, \quad \Delta \Gamma = \text{predicted partial rate in the reduced phase space}$$

V_{ub} Inclusive Measurement: Strategy

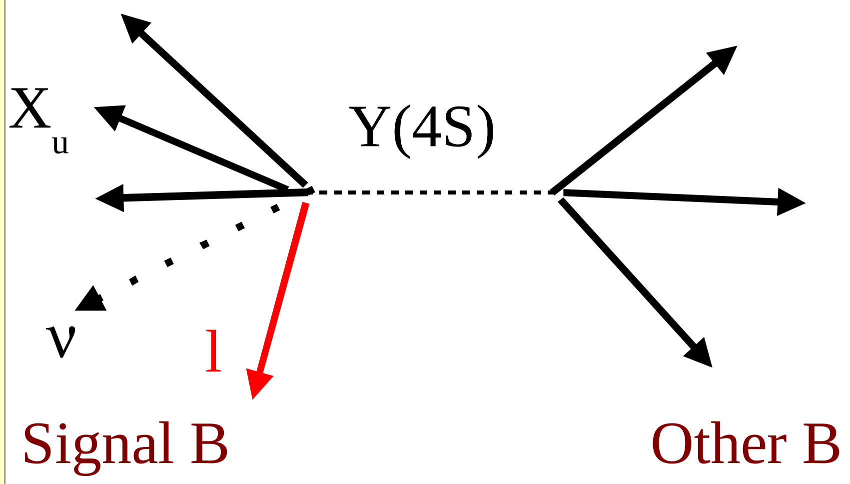
STUDY

Inclusive kinematic variables:

➔ Lepton momentum spectrum near kinematic endpoint (small acceptance)

➔ M_X (high acceptance & BKG)

➔ M_X vs q^2, E_l vs q^2 (medium acceptance, reduced BKG)



USING

➔ Recoil of Fully Reconstructed $B \to D^{(*)}X$ (clean environment, small sample)

➔ Untagged B (high efficiency, crucial BKG modeling)

Endpoint Analyses

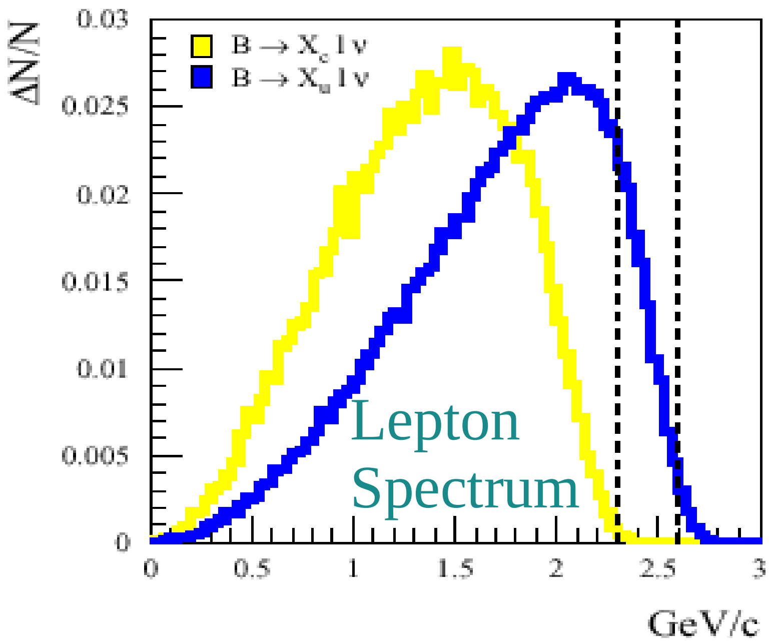
➔ High energy electron
2.0 GeV/c<Pe<2.6 GeV/c

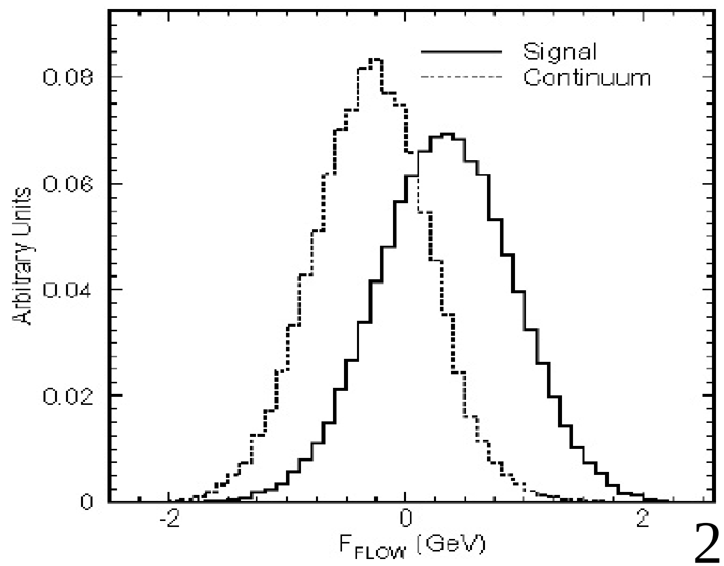
➔ P_{miss}, event shape cuts

➔ S/B~1/14 ➔ BKG modeling crucial

➔ BB BKG:
$X_c l\nu$: fitted (D, D^*, D^{**}) relative amount
J/Ψ, γ conversions: veto on inv. mass
Fakes: estimated from Ks $\rightarrow \pi^+\pi^-$

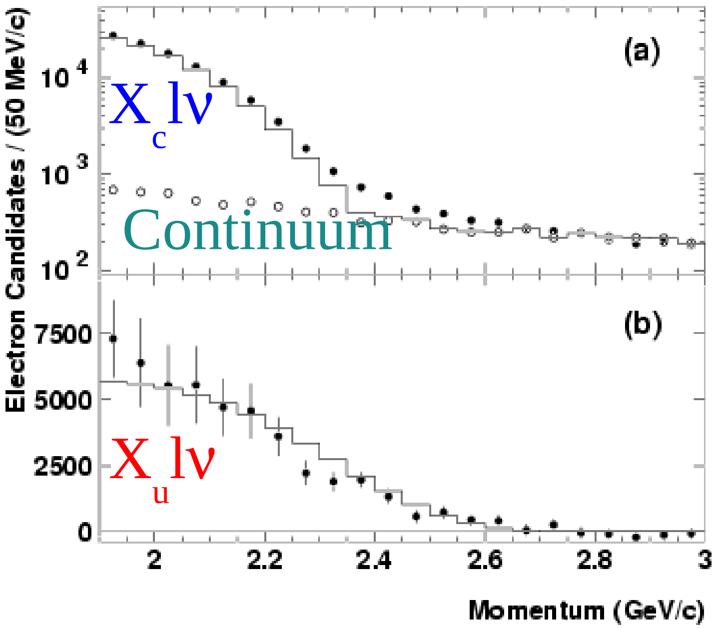
➔ Non BB BKG (continuum+QED):
suppressed by Eflow, Evis, event shape requirements;
measured on off−resonance & on−resonance (Pe>2.8 GeV/c)



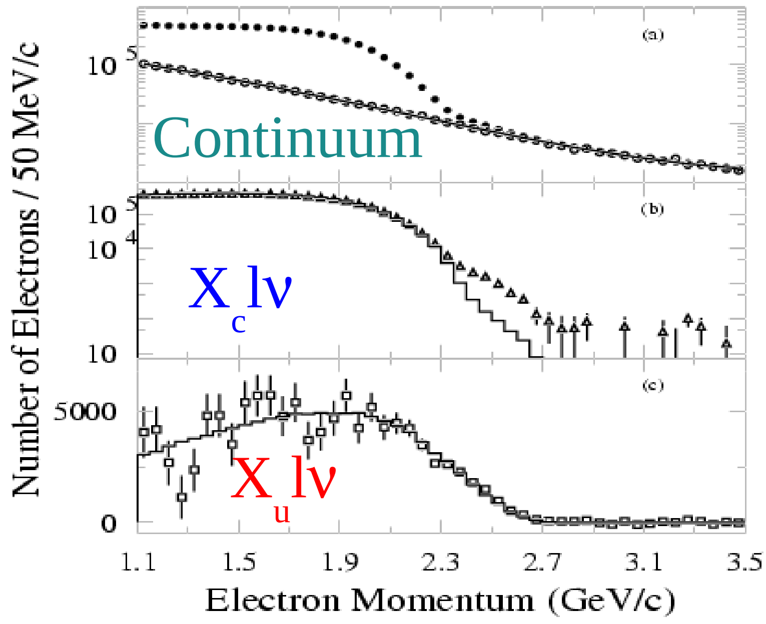


Endpoint Analyses

Belle (Pe>1.9, 27 fb^{-1})



BaBar (Pe>2.0, 80 fb^{-1})



V_{ub}(DFN)×10^3 $5.01\pm0.47_{exp}\pm0.36_{fu}\pm0.24_{OPE}$ $4.40\pm0.24_{exp}\pm0.28_{fu}\pm0.21_{OPE}$

[BaBar: hep−ex/0408075]

V_{ub}(BLNP)×10^3 $4.49\pm0.42_{exp}\pm0.32_{SF}\pm0.20_{theo}$

[Belle: hep−ex/0504046]

➔Dominant systematics from $X_c l\nu$ description & kinematic acceptance f_u

➔BLNP result lower, same global precision ~13%

BaBar ν reco Analysis (80 fb−1)

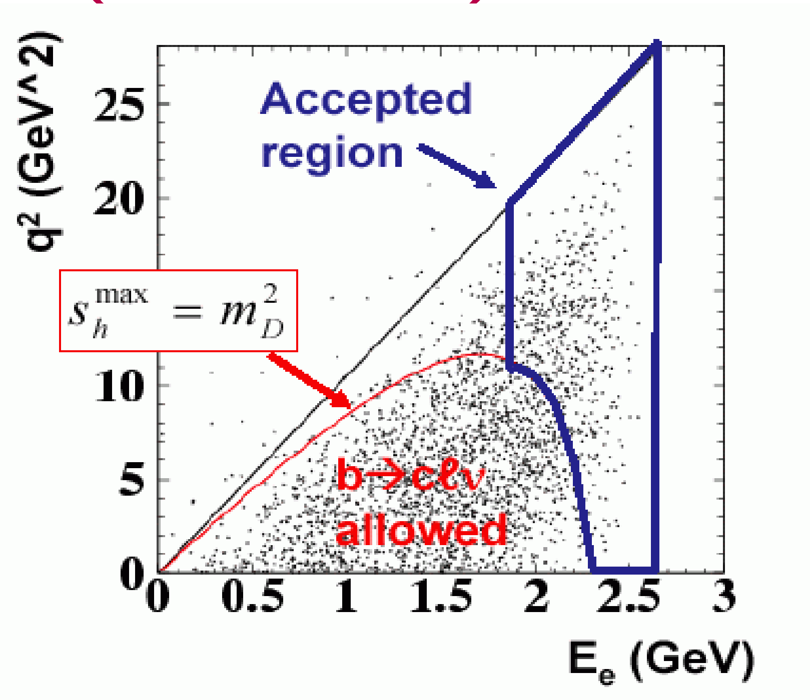
➔Endpoint Analysis sample with harder cuts (P_{miss}, event shape)

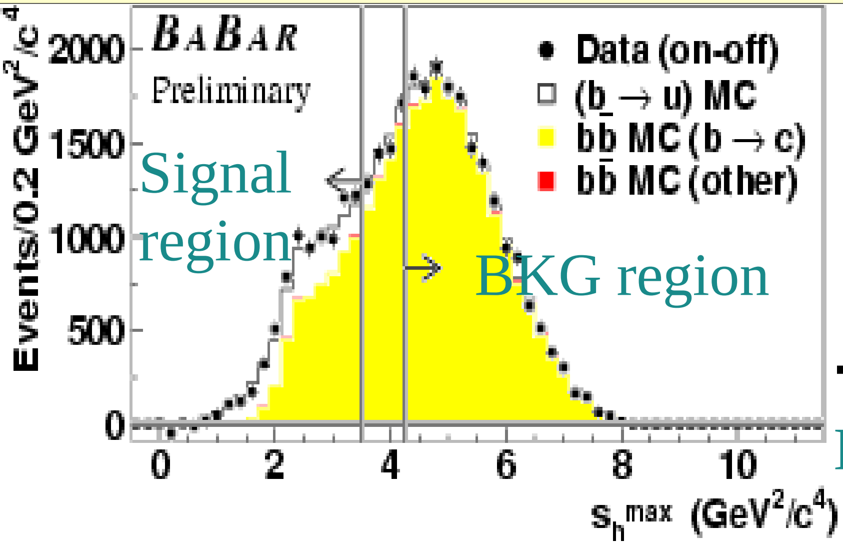
➔ν reconstruction based on P_{miss} checked on $D^{(*)}l\nu$ control sample

➔Discriminant variable: Maximum kinematically allowed hadronic mass $s_h^{max}(Ee, q^2)$

➔Reduced (25%) acceptance, but S/N~1/2

➔Signal Region: Ee>2GeV, $s_h^{max}<3.5\mathrm{GeV}^2/c^4$

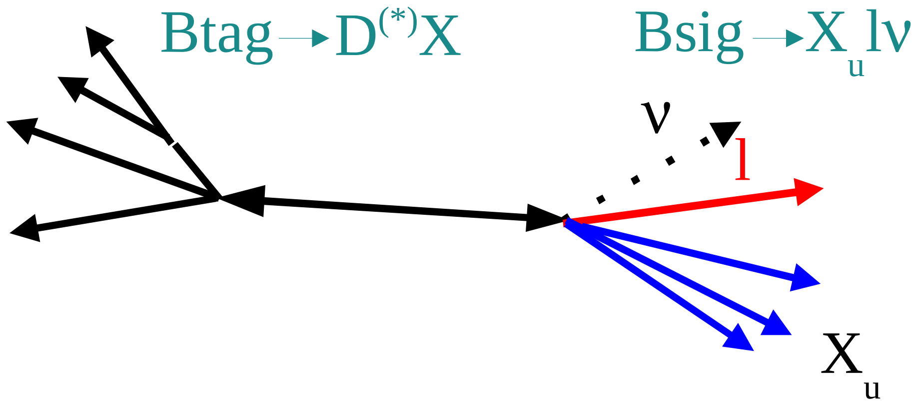




$Vub=(4.99\pm0.49_{exp}\pm0.16_{fu}\pm0.22_{OPE})10^{-3}$
[hep−ex/0408045]

➔Systematics from neutrals & K_L, $X_c l\nu$ BKG, Ee cut

Hadronic Tag Analyses



➔Fully reconstruct Btag hadronic Decay (hundreds of modes)

➔ε=0.3%−0.4%

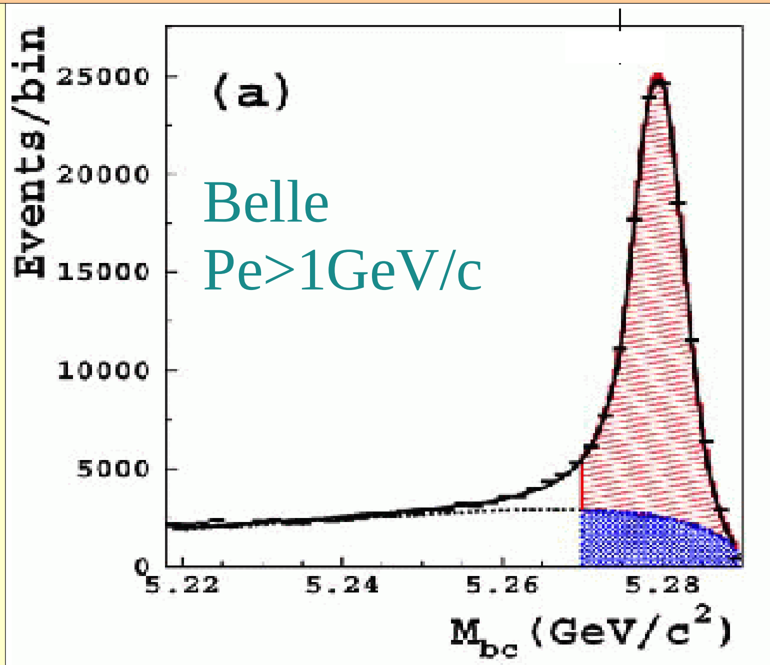
➔$X_c l\nu$ suppression (kinematical/topological cuts)

➔Look for high P lepton in the recoil

➔Charge correlation, K veto in signal region, M_{miss} cuts

➔Study inclusive kinematical variable (M_X, q^2, M_X vs q^2, $P_+=E_X-P_X$)

➔BR from a fit with expected distributions for $X_c l\nu$ & $X_u l\nu$ components

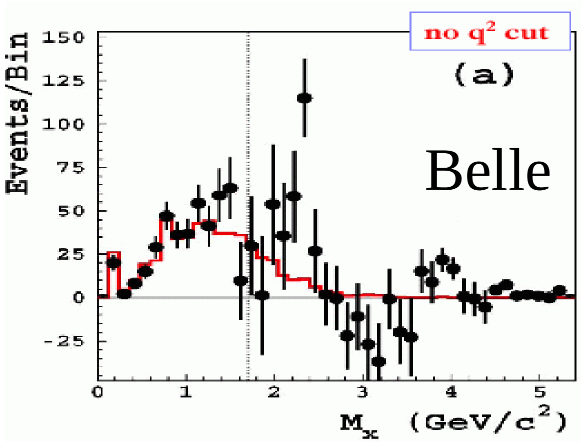


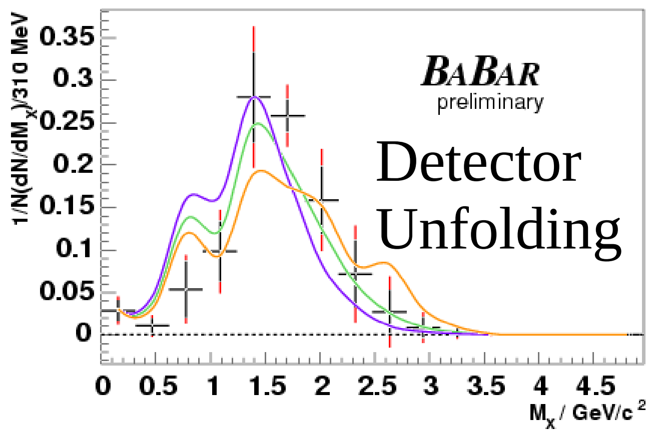
Hadronic Tag Analyses

➔M_X fit (no q^2 cut): Belle(253 fb^{-1},BLNP) BaBar(80 fb^{-1},DFN)

[Belle: hep−ex/0505088] [BaBar:hep−ex/0408068]

$Vub\times10^3=4.35\pm0.29_{exp}\pm0.40_{SF}\pm0.16_{theo}$ $5.22\pm0.43_{exp}\pm0.21_{fu}\pm0.25_{OPE}$

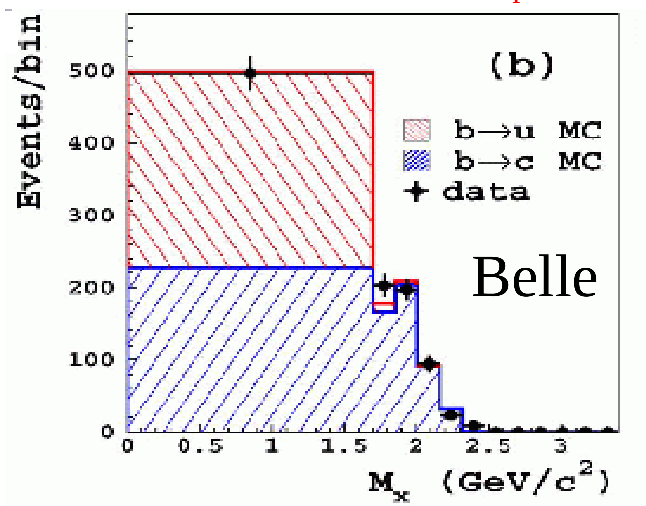


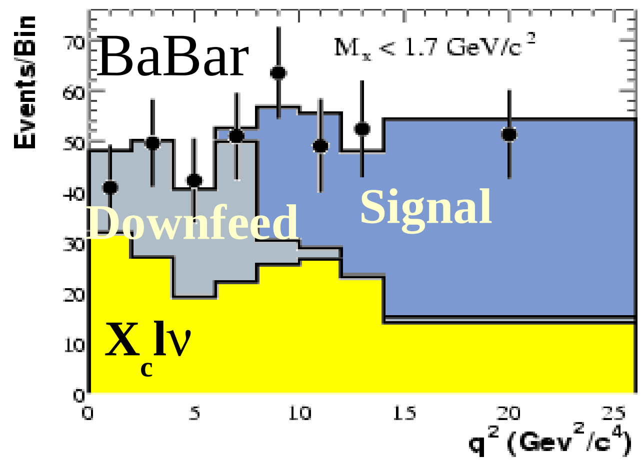


➔Moments sensitive to theory parameters

➔(M_X<1.7GeV, q^2>8GeV^2) 2D fit, reduced dependence on SF:

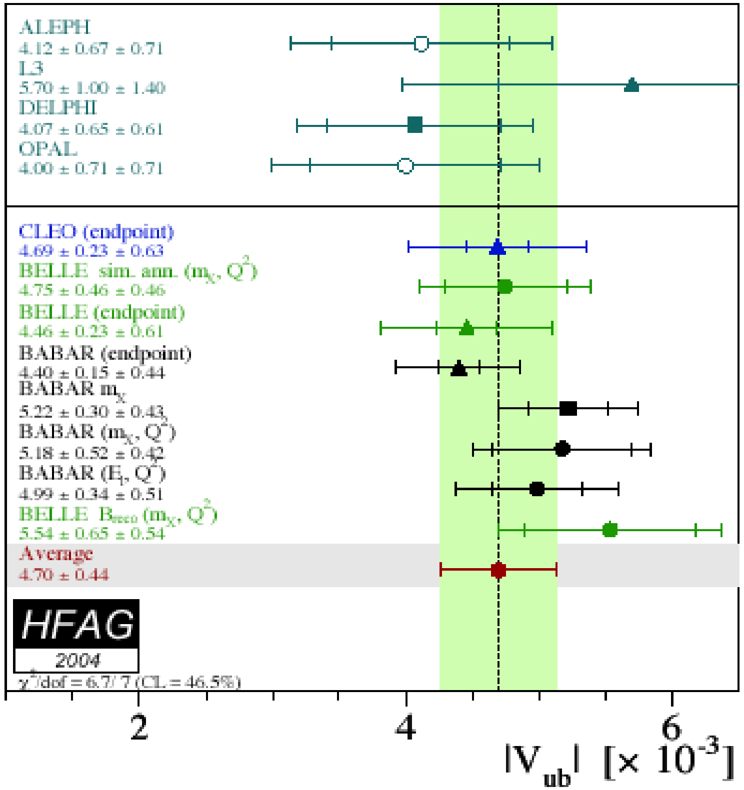
$Vub\times10^3=4.93\pm0.39_{exp}\pm0.46_{SF}\pm0.26_{theo}$ $4.98\pm0.56_{exp}\pm0.47_{theo}$ (BLL)





➔Systematics from $X_{c(u)}l\nu$ model, detector, BKG subtraction

V_{ub} Inclusive Measurements: Summary



➔Vub world average= $4.70\pm0.44\times10^{-3}$

➔Endpoint measurements systematically limited; will improve factor~2 with 0.5 ab^{-1}

➔Tagged Analyses will improve statistical error by factor~3

➔Working on new kinematic variables (P_+, WA):

Belle $P_+ = E_X - P_X$:

$Vub\times10^3 = 4.56\pm0.39_{exp}\pm0.47_{SF}\pm0.16_{theo}$

➔Reducing theoretical error is challenging

➔BLNP model:
shows larger sensitivity to SF than DFN; Vub ~5−10% lower

➔SF parameters:
BaBar $b\to cl\nu$ moments vs Belle $b\to s\gamma$ spectrum: ~10–20% lower

V_{ub} Exclusive Measurements: Theory

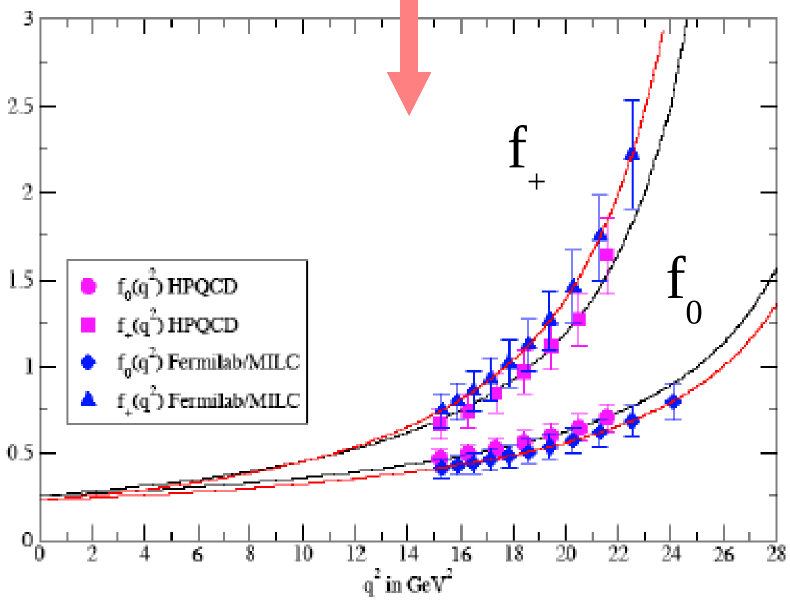
$$\frac{d\Gamma(B\to\pi(\rho)l\nu)}{dq^2}=\frac{G_F^2V_{ub}^2}{24\pi^3}f(q^2)^2p_\pi^3\ ;Vub=\sqrt{\frac{BR(B\to\pi l\nu)}{\Gamma_{thy}\tau_B}},\quad \Gamma_{thy}\text{=FF normalization}$$

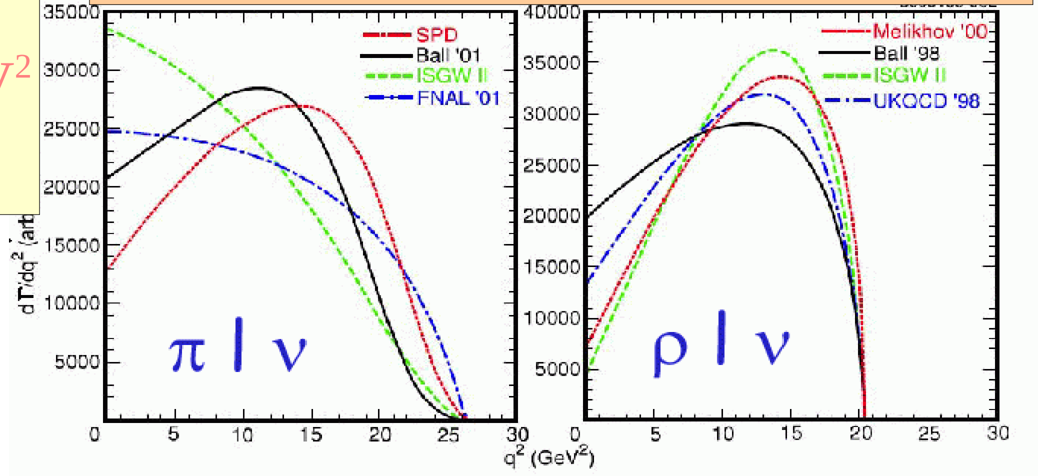
Two new unquenched LQCD results [FNAL'04/HPQCD'04]

➔ $B\to\pi l\nu$ only; reliable for $q^2>15$ GeV^2

➔ Uncertainty~ 10−14% level

FF from quenched LQCD:
Uncertainties in rate & normalization





➔ Light−Cone−Sum−Rules [Ball, Zwicki'04]: reliable for $q^2=(P_l+P_\nu)^2<15$ GeV^2

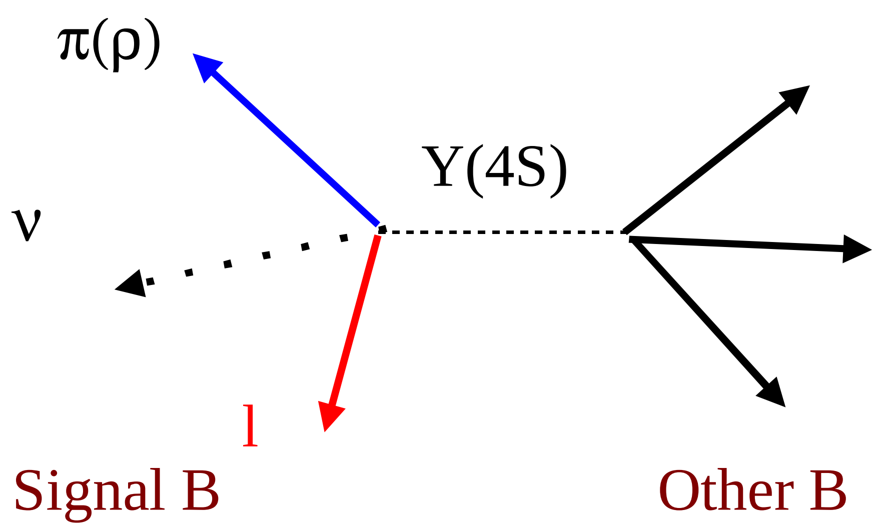
Further progress foreseen:

➔ LQCD: expect ~6−7% total theory error on V_{ub}

➔ Try to measure FF(q^2) on data

V_{ub} Exclusive Measurement: Strategy

Measure BR($b \to X_u l\nu$) and V_{ub} using:



➔ Recoil of Fully Reconstructed $B \to D^{(*)}X$ (very low statistics & BKG $X_u = \pi, \rho, \omega, \eta, a^0$);

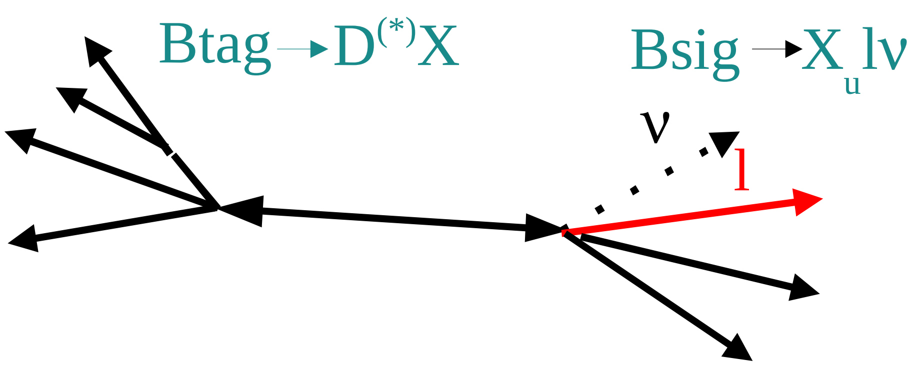
➔ Recoil of $B \to D^{(*)} l\nu$ (medium efficiency, good S/N several analyses);

➔ Untagged B (high statistics & BKG, gives best precision now);

➔ Experimental goal: q^2 distribution with minimum FF dependence in the rate

➔ V_{ub} from limited region of q^2 spectrum (reliable theoretical FF estimations)

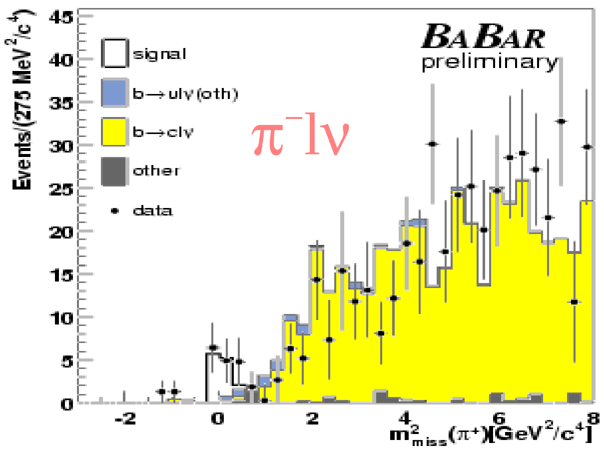
BaBar Full Reco Analysis (80 fb^{-1})

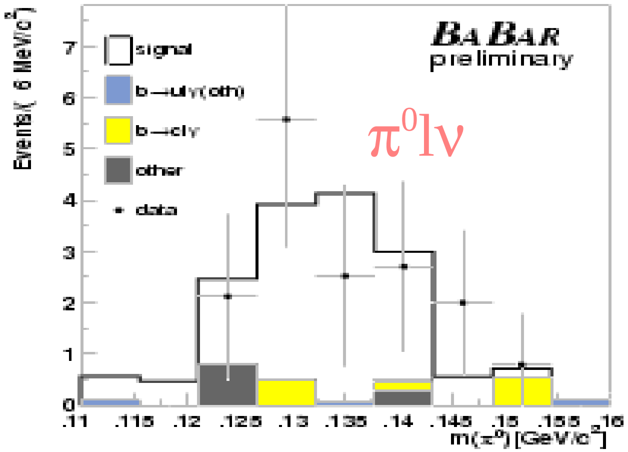


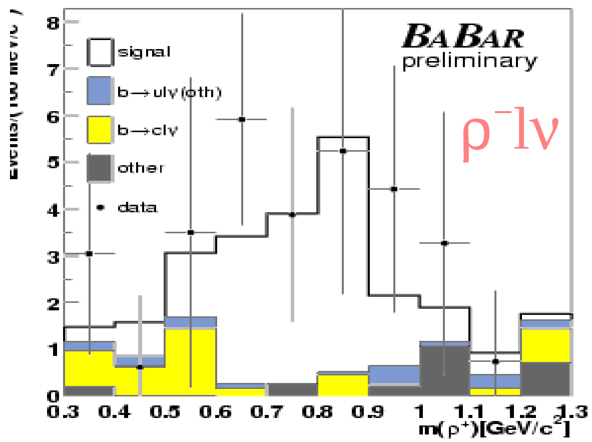
➔Fully reconstruction of Btag hadronic decays as for Inclusive Analysis

➔9 $B \to X_u l\nu$ modes exclusively reconstructed on recoil ($X_u = \pi^{0(+)}, \rho^{0(+)}, \omega, \eta, \eta', a_0^{0(+)}$)

➔Charm BKG rejection optimized mode by mode







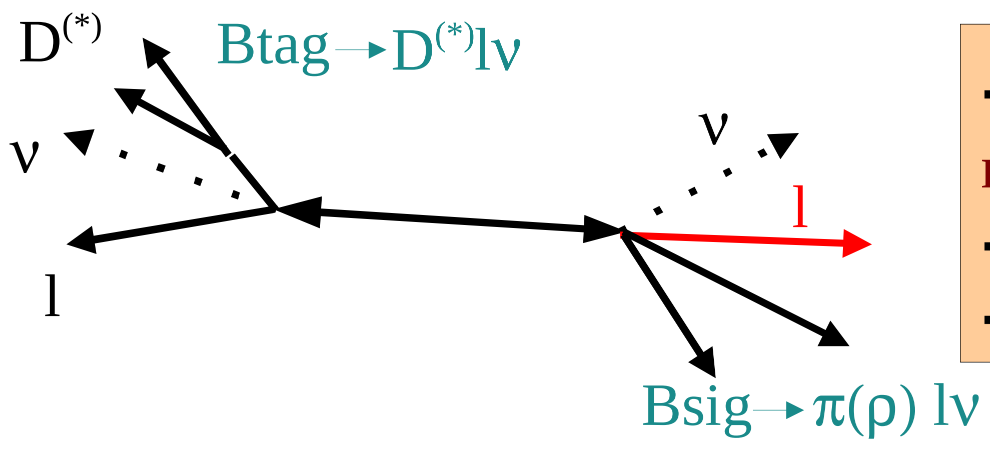
$BR(B^0 \to \pi^- l^+ \nu) = (1.08 \pm 0.28 \pm 0.16) \times 10^{-4}$

$BR(B^0 \to \rho^- l^+ \nu) = (2.57 \pm 0.52 \pm 0.59) \times 10^{-4}$ Upper limits on ω, η, η', a_0

[hep−ex/0408068]

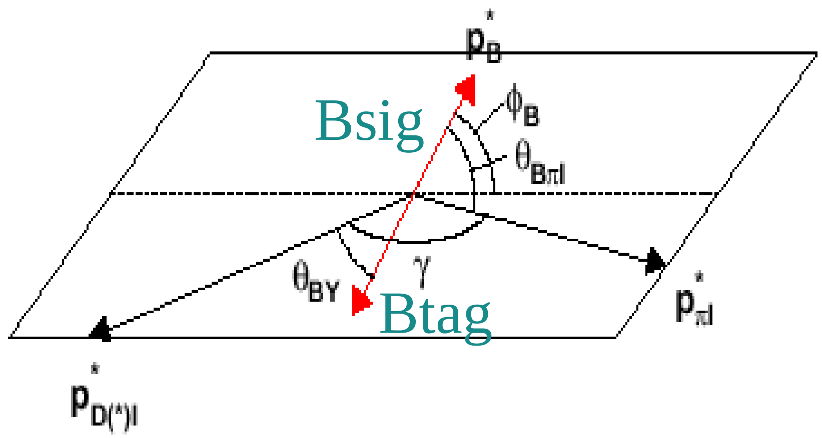
➔Systematics from MC statistics & $B \to \rho^0 l\nu$ non−resonant irreducible BKG

V_{ub} Semileptonic Tag Analyses



- ➔Study semileptonic recoil wrt reconstructed $B \to D^{(*)}l\nu$;
- ➔ε~x4 higher than hadronic decay tag
- ➔S/N>2

➔Discriminant variables: Btag−$D^{(*)}$l & Bsig−πl angles:

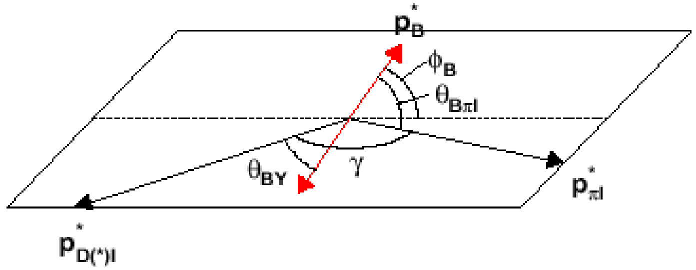


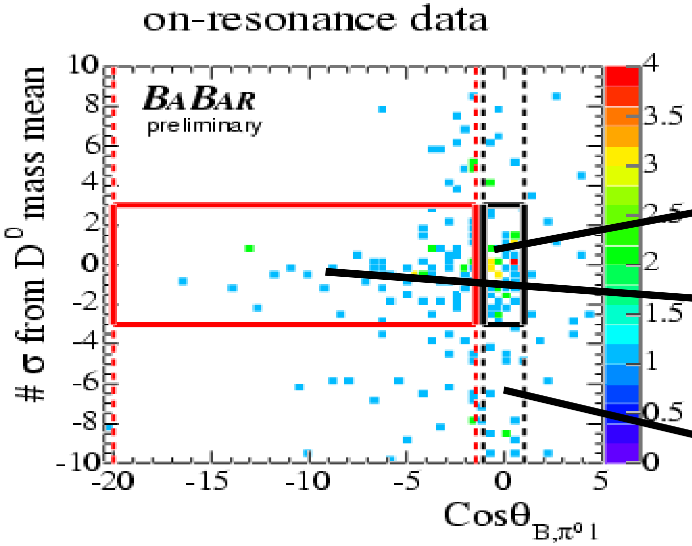
➔Using only signal−side kinematic:
BaBar BR($B^+ \to \pi^0 l^+ \nu$)

➔B mesons direction exploiting kinematic of double (Btag & Bsig) semileptonic decay:
BELLE & BaBar BR($B^0 \to \pi^- l^+ \nu$)

BaBar SL Tag $\pi^0 l\nu$ Analysis (82 fb^{-1})

→ Cut & count in ($\cos\theta_{B,\pi l}$, M_{D0}) plane

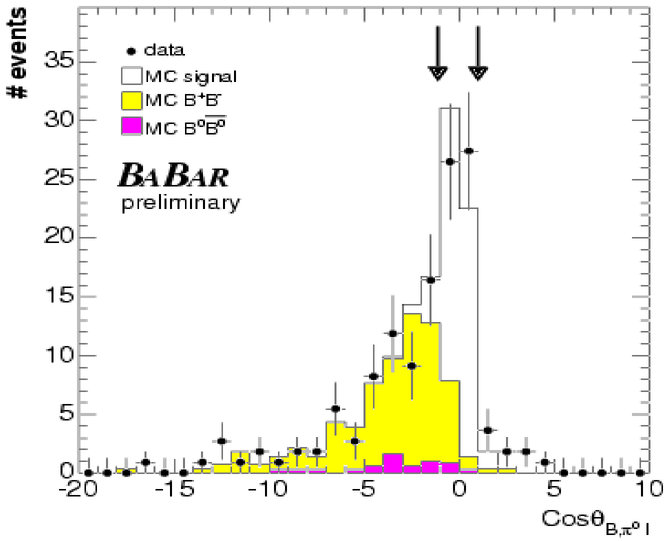




Signal region

Peaking BKG region for $B^+ \rightarrow h\,l\,\nu$ ($M_h > M_{\pi^0}$) subtraction

Side bands region for combinatorial BKG subtraction



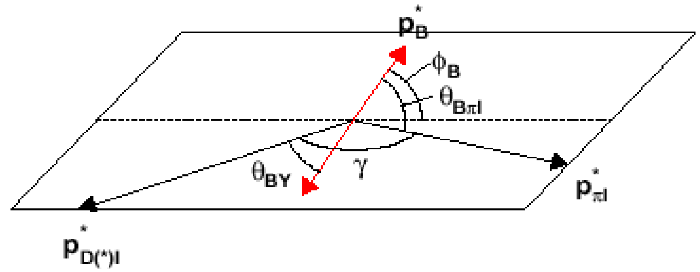
Systematics	$\sigma_{\mathcal{B}}/\mathcal{B}$
Signal Efficiency	$\pm 6.0\%$
Tagging Efficiency	$\pm 3.9\%$
$B\bar{B}$ Background Subtraction	$\pm 7.6\%$
Total Error	$\pm 12.9\%$

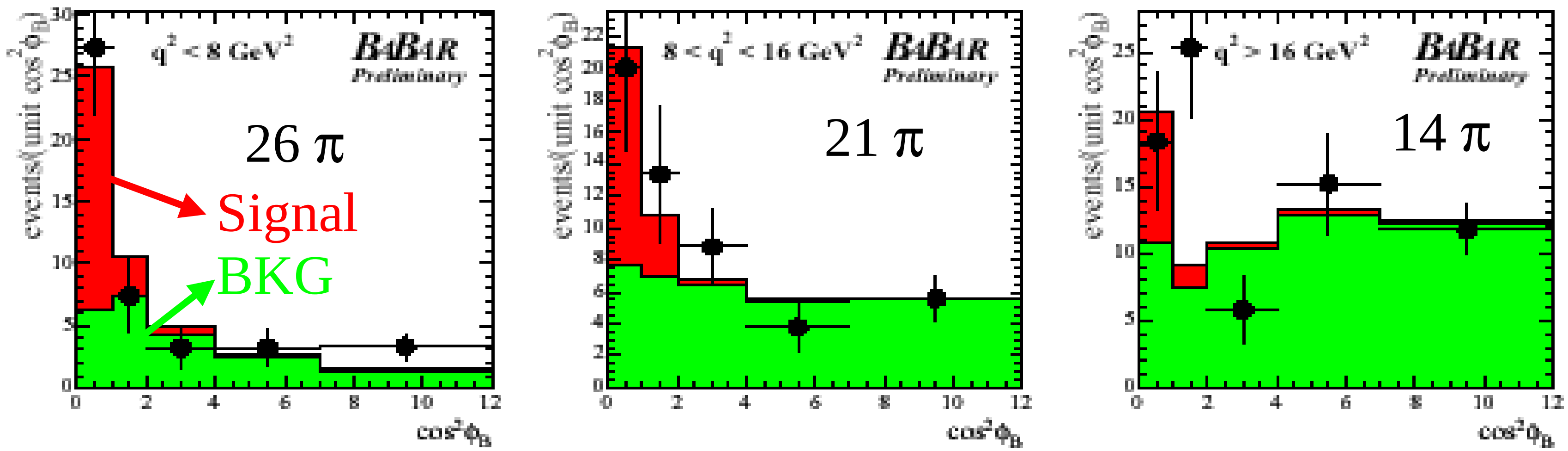
$BR(B^+ \rightarrow \pi^0 l^+ \nu) = (1.80 \pm 0.37 \pm 0.23) \times 10^{-4}$

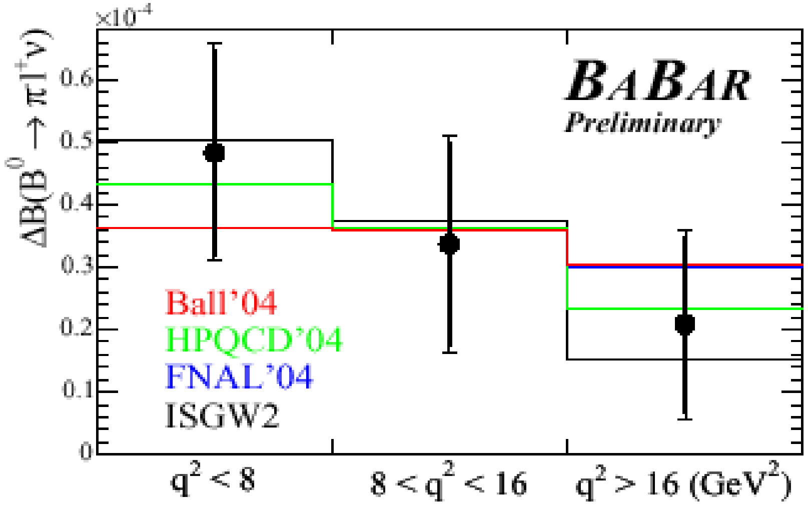
BaBar SL Tag $\pi^- l^+ \nu$ Analysis (211 fb^{-1})

➔ Discriminant variable: Φ_B angle

➔ Signal yields from a fit in three q^2 bins:







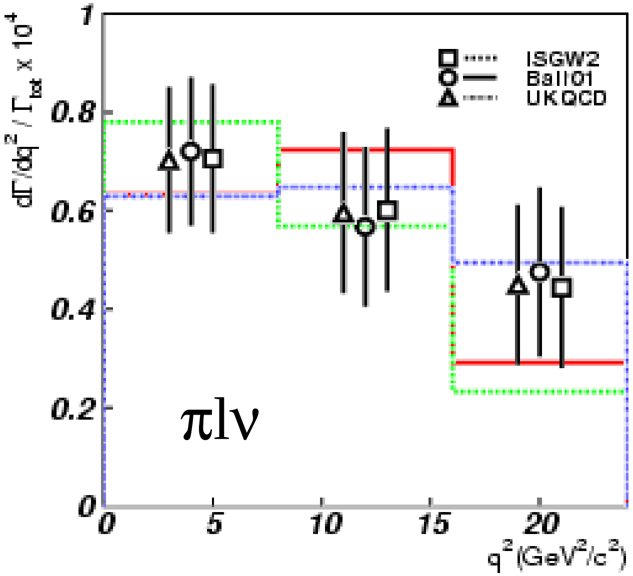
$BR(B^0 \to \pi^- l^+ \nu) = (1.03 \pm 0.25 \pm 0.13) \times 10^{-4}$

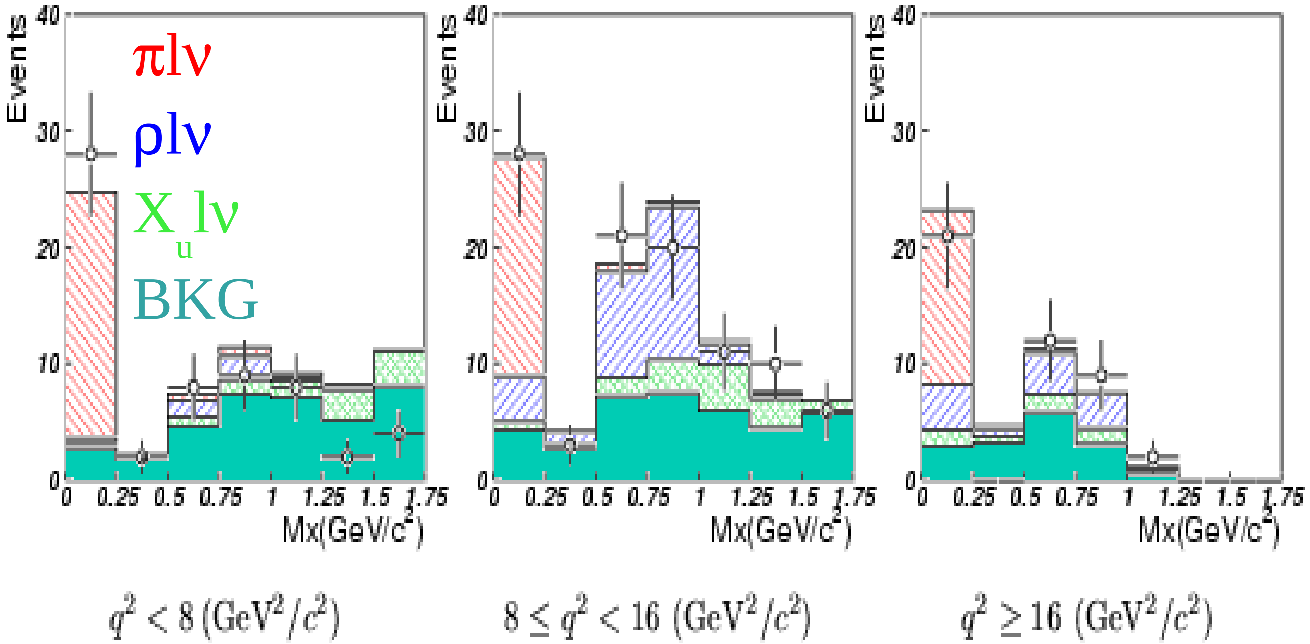
➔ Systematics from tagging, BB BKG, $BR(B \to X_c l\nu)$, $BR(B \to \rho l \nu)$

Belle SL Tag $\pi^- l^+ \nu$ Analysis (140 fb^{-1})

➔ $B_{sig} \to X_u l\nu$ ($X_u = \pi$, $\rho \to \pi\pi^0$), $P_l > 0.8$ GeV/c

➔ Discriminant variables: mX_u, B meson direction





$BR(B^0 \to \pi^- l^+ \nu) = (1.76 \pm 0.28 \pm 0.20 \pm 0.03(FF)) \times 10^{-4}$

$V_{ub}^{[quen]} = 3.90 \pm 0.75\,^{+0.62}_{exp-0.46} \times 10^{-3}$

$V_{ub}^{[HPQCD]} = 4.73 \pm 0.89\,^{+0.74}_{exp-0.50} \times 10^{-3}$

$V_{ub}^{[FNAL]} = 3.87 \pm 0.73\,^{+0.85}_{exp-0.51} \times 10^{-3}$ [hep−ex/0408145]

➔ V_{ub} from highest q^2 bin

➔ Dominant Systematics from double SL decay reconstruction & BB BKG shape

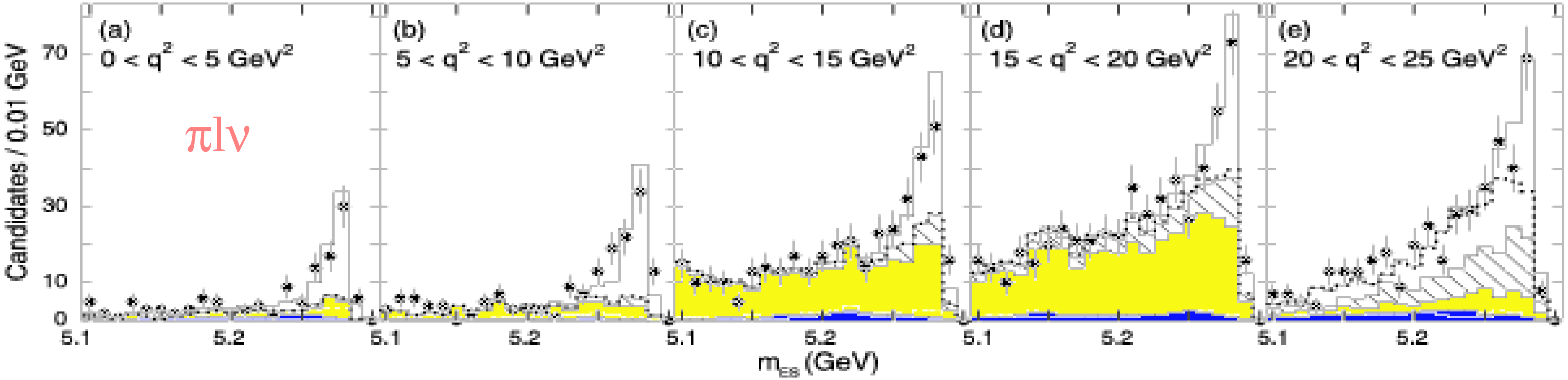
BaBar Untagged Analysis (76 fb^{-1})

➔ π^+, π^0 selected, p_l>1.3 GeV/c, p_{miss}>0.7 GeV/c

➔ Neutrino reconstruction from full event:

$$(\vec{p}_{miss}, E_{miss}) = (\vec{p}_{beams}, E_{beams}) - (\sum \vec{p}_i, \sum E_i)$$, $M^2_{miss}/2E_{miss}$ <0.4 GeV

➔ BKG charm suppression by means of kinematical & topological cuts



➔ Assuming isospin relation $\Gamma(B^0 \to \pi^- l^+ \nu) = 2\Gamma(B^+ \to \pi^0 l^+ \nu)$:

$BR(B^0 \to \pi^- l \nu) = (1.38 \pm 0.10 \pm 0.17 \pm 0.08) \times 10^{-4}$

➔ From LQCD (high q^2):

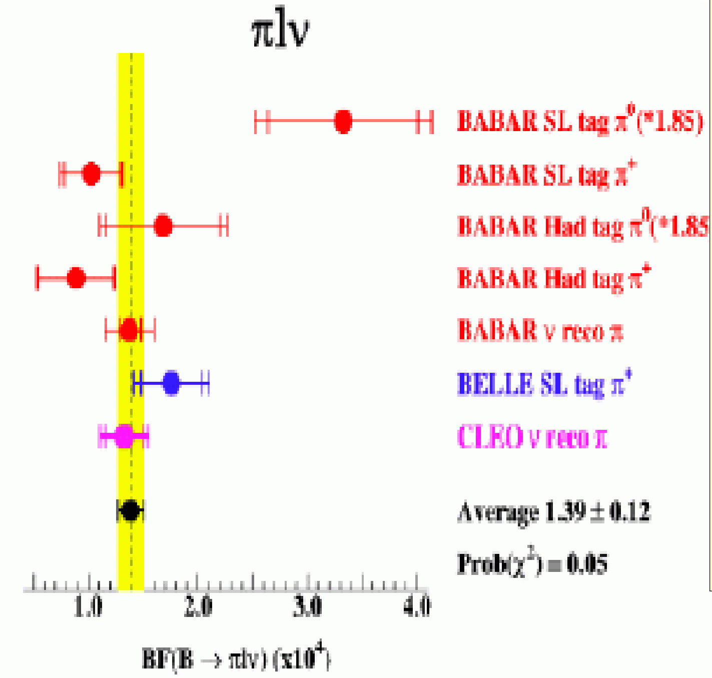
$Vub = (3.82 \pm 0.14 \pm 0.24 \pm 0.11^{+0.88}_{-0.52}) \times 10^{-3}$

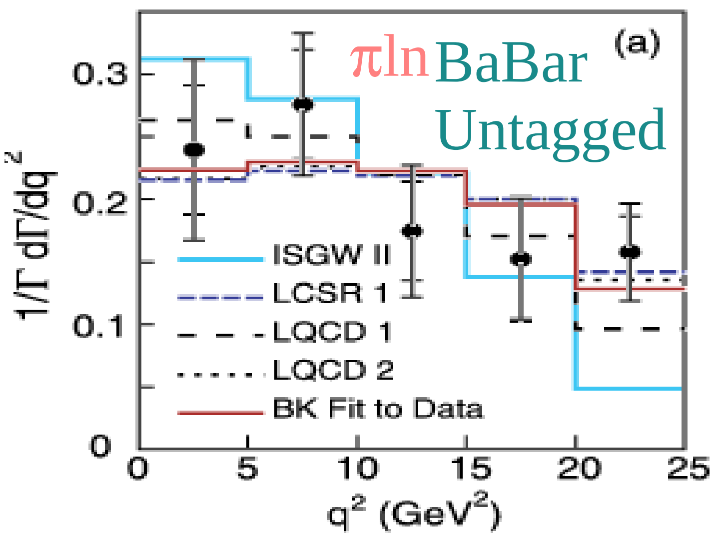
FF Shape

FF normalization

➔ Exp. Systematics from ν reconstruction & $b \to c(u) l \nu$ BKG

V_{ub} Exclusive Measurements: Summary





➔Several $b \rightarrow u l \nu$ measurements in bins of q^2
(LCSR q^2<16 GeV^2, LQCD q^2>16 GeV^2)
➔Untagged analysis currently most precise

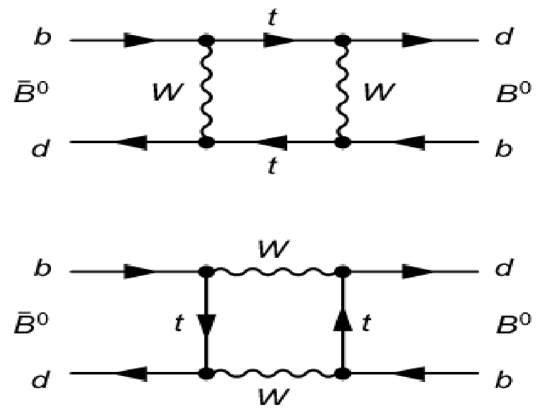
➔Future: V_{ub} uncertainty depends on LQCD & ability to increase q^2 acceptance; measure $FF(q^2)$ on data
➔Expect δV_{ub} ~10% total error with 0.5 ab^{-1}

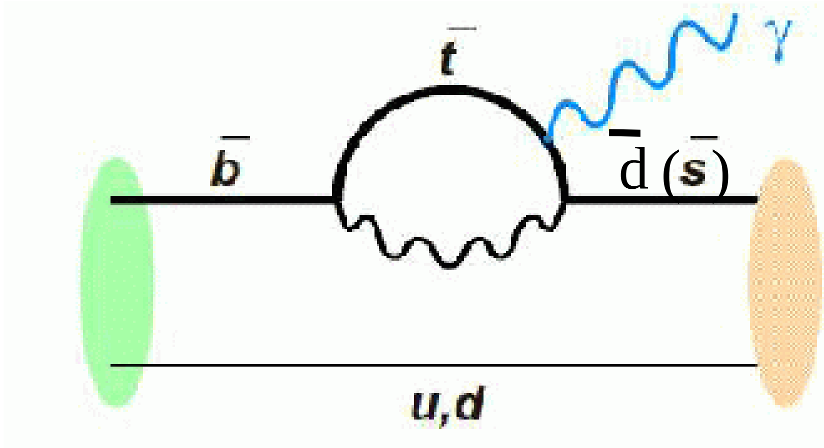
➔BaBar Untagged Analysis: fit $FF(q^2)$ shape on data using the Becirev/Kaidalov parameterization:

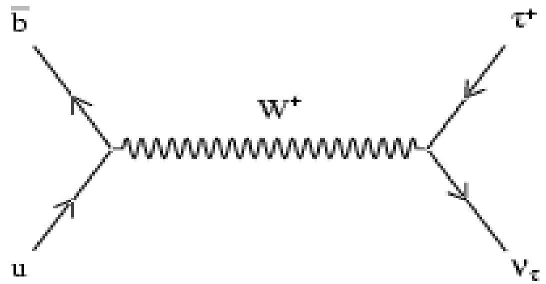
$$f(q^2) = \frac{c_B(1-\alpha)}{(1-q^2/m_B^2)(1-\alpha q^2/m_B^2)}$$

➔$\alpha = 0.60 \pm 0.15$
(HPQCD: α=0.42, FNAL: α=0.62)

V_{td}, V_{ts} Measurements at B factories







V_{td} from B^0 Mixing:

- ➔Very small experimental error
- ➔big theoretical uncertainty

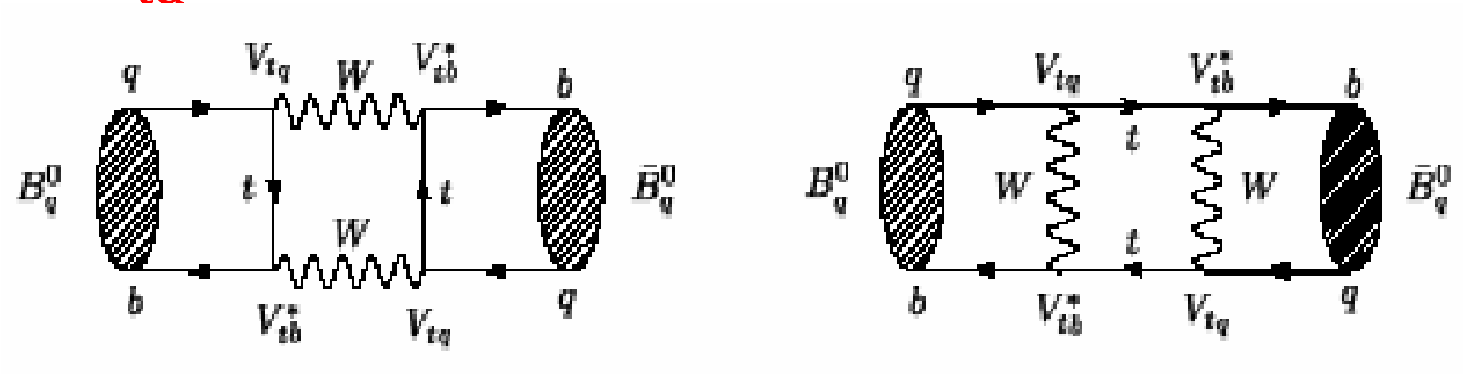
Radiative B decays:

- ➔Sensitive to New Physics
- ➔$b \to s\gamma$ extensively studied: BR, charge/isospin asymmetry, CP violation in mixing
- ➔$b \to d\gamma$ not observed yet: search for $B \to \rho\gamma$, $\omega\gamma$ $|V_{td}/V_{ts}|$ from $BR(b \to \rho\gamma)/BR(b \to K^*\gamma)$

Pure leptonic B^+ decay:

- ➔$|V_{ub}/V_{td}|$ from $BR(B^+ \to \tau^+\nu_\tau)$ & Δm_d

V_{td} Measurements: $B^0 \overline{B}^0$ Mixing



➔Mass difference between mass eigenstates $\Delta m_{d(s)}$ quantifies neutral $B_{d(s)}$ mixing

➔At B−factories: only B_d accessible:

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{Bd} \hat{B}_{Bd} F_{Bd}^2 \eta_B m_W^2 S_0(x_t) |V_{td}|^2$$

➔Bag factor & meson decay constant from LQCD dominate theoretical error

$B_{Bd}^{1/2} F_{Bd} = 214 \pm 38$ MeV

[Hashimoto04/CKM2005]

➔$\delta_{th} V_{td} \sim 20\%$ from Δm_d ($\delta_{exp} V_{td} \sim 0.5\%$)

➔Including Δm_s

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

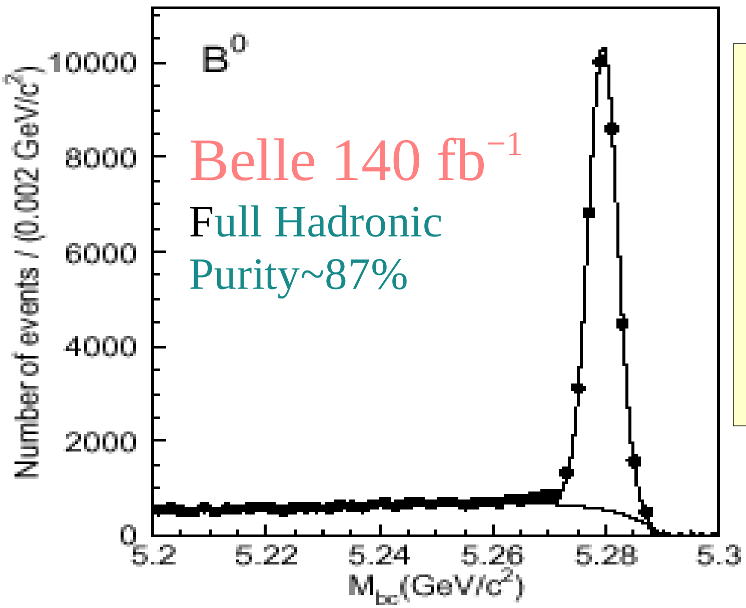
➔short distance & many lattice uncertainties cancel

$\xi = 1.23 \pm 0.06$

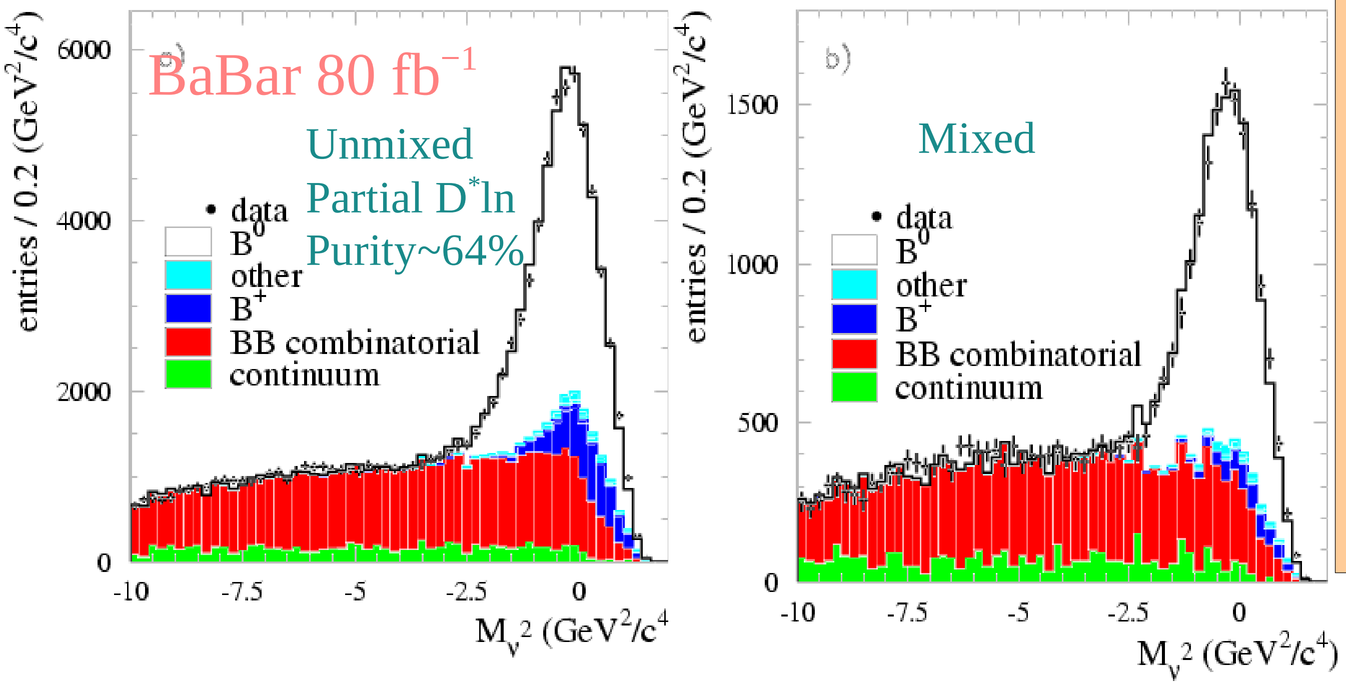
[Hashimoto04/CKM2005]

➔$\delta_{th} |V_{td}/V_{ts}| \sim 5\%$

Mixing & lifetime 2D Analyses



➔Belle (140 fb^{-1}): B^0 decays fully reconstructed in hadronic & semileptonic modes:
$B^0 \to D^{(*)}\pi$, $D^{(*)}\rho$, $J/\Psi K^{0(*)}$, $D^* l\nu$
➔Other B flavor−tagged using charged leptons, K, π, Λ

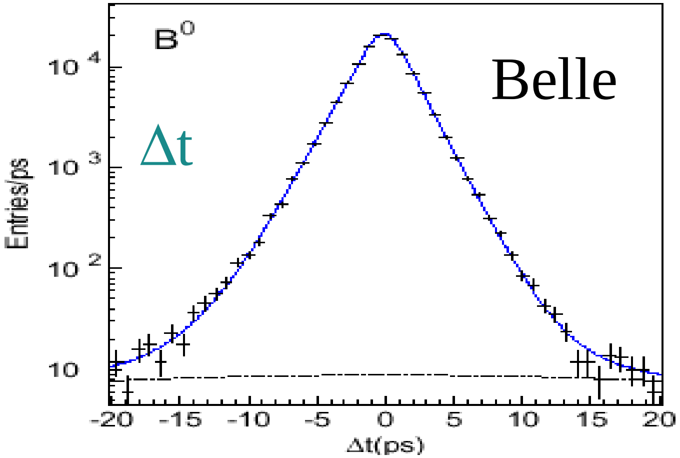


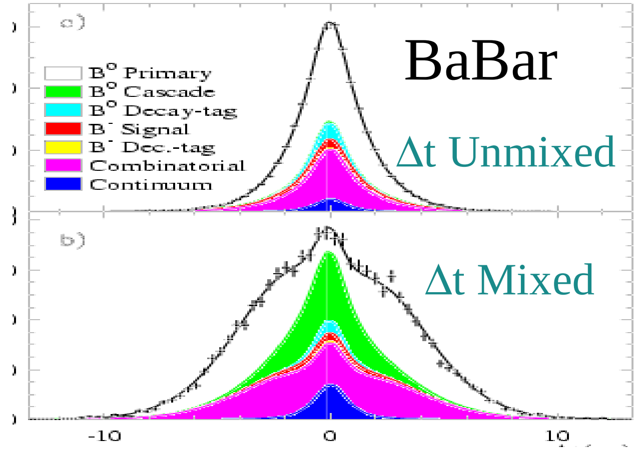
➔BaBar (80 fb^{-1}):
$D^* l\nu$ P.R.
Using lepton & π

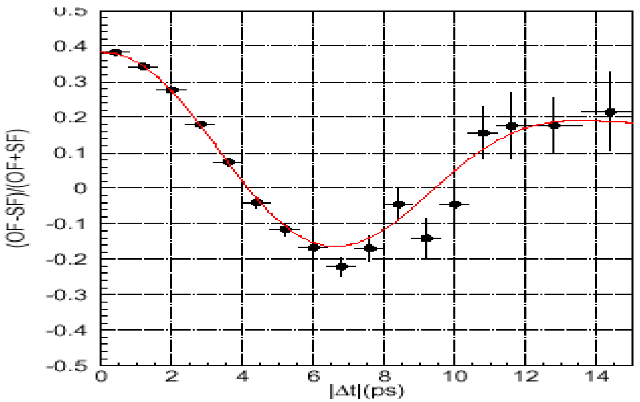
➔Discriminant variable $M^2\nu$ from D^* & lepton 4−momentum
➔Flavor tag from high P lepton from the Btag

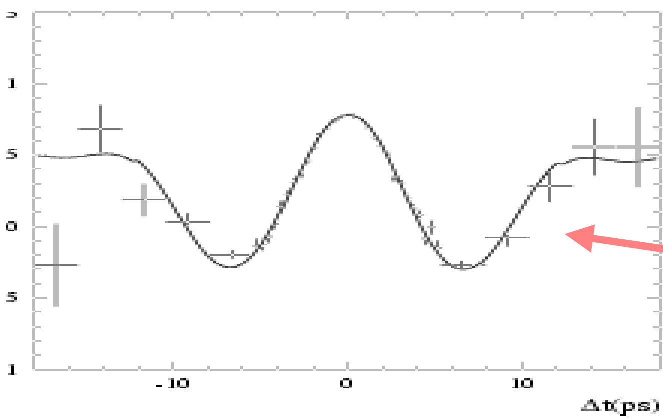
Mixing & lifetime 2D Analyses

➔Unbinned simultaneous fit to Unmixed/Mixed Δz distributions with resolution & mistag free parameters









➔Babar Systematics from alignment, bias, stability

➔Belle Systematics from $D^{**}l\nu$ BKG, vertex reconstruction

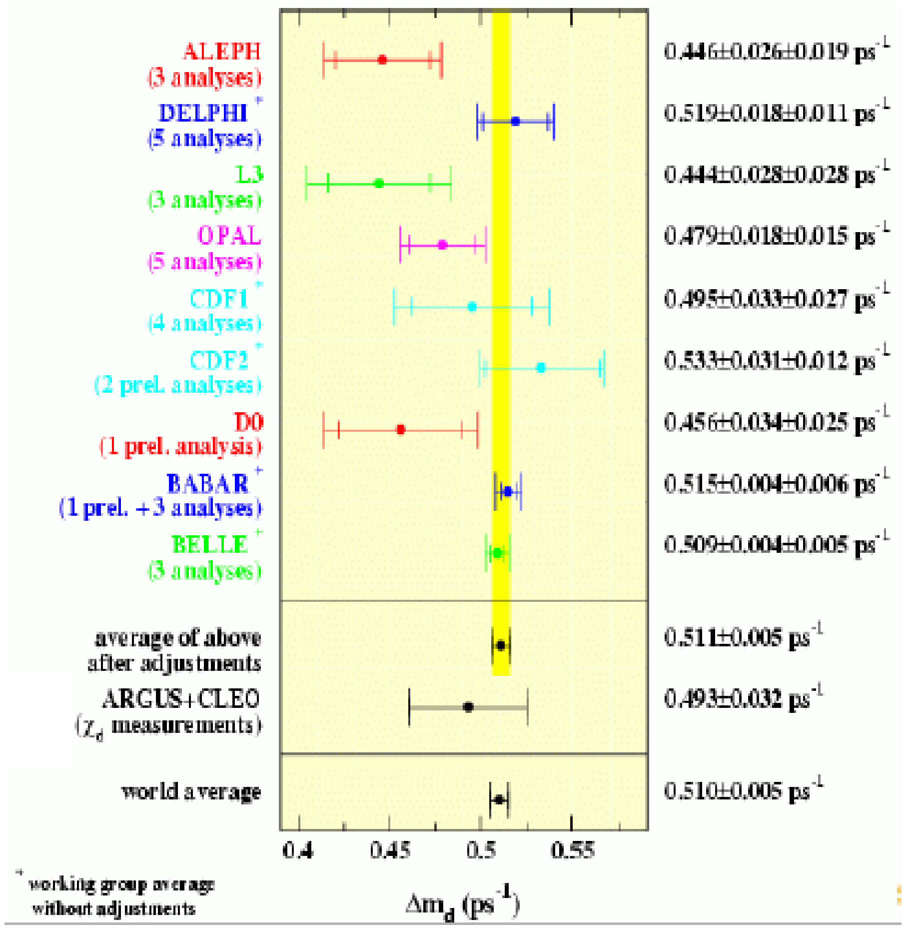
Asymmetry: $(N^{+-}-N^{++})/(N^{+-}+N^{++})$

$\tau(B^0)$= 1.534±0.008±0.010 ps 1.504±0.013±0.015 ps

Δm_d = 0.511±0.005±0.006 ps^{-1} 0.511±0.007±0.007 ps^{-1}

[PRD 71 072003]

V_{td} from Mixing: Summary



➔From World Average

$\Delta m_d = 0.510 \pm 0.005\ \text{ps}^{-1}$

➡ $V_{td} = 0.0087 \pm 0.0017$

➔$\delta_{exp}(\Delta m_d)$ contributes only 0.5% to V_{td} error

$\delta_{theo}(\Delta m_d) \sim 20\%$

➔Using Δm_s lower limit

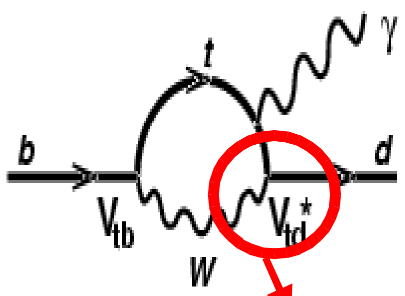
$\Delta m_s > 14.5\ \text{ps}^{-1}$ (95% CL)

➡ $V_{td}/V_{ts} < 0.23$

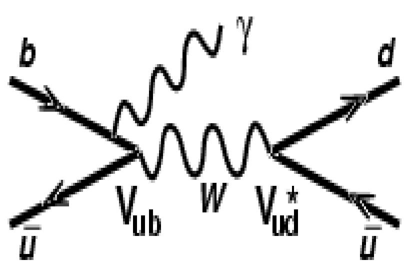
V_{td}/V_{ts} from BR($b \to d\gamma$)/BR($b \to s\gamma$)

Inclusive Measurements VS Exclusive Measurements

➔Smaller theoretical error (no hadronization effects), experimentally hard ($MK^* \sim M\rho$): no endpoint, huge $b \to s\gamma$ BKG: Super B−Factory?



$$\left|\frac{V_{td}}{V_{ts}}\right|^2 \sim 0.04$$



➔Experimentally easier, need FF

➔ρ^0/K^{*0} theoretically cleanest modes, reduced FF uncertainties via ratio:

$$R_0 = \frac{BR(B \to \rho\gamma)}{BR(B \to K^*\gamma)} = \frac{K}{2\xi^2}\left|\frac{V_{td}}{V_{ts}}\right|^2 (1+\Delta)$$

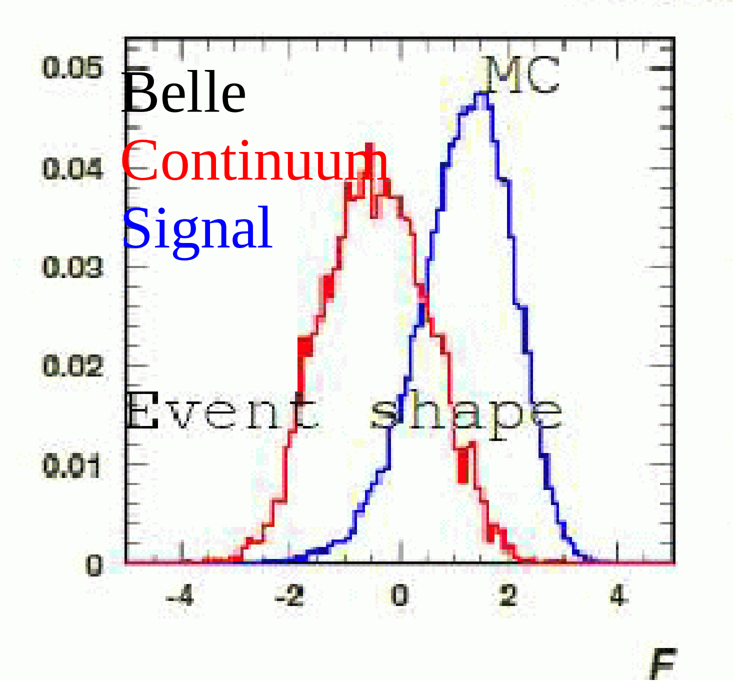
➔K=kinematic factor~1.023

➔Δ(SM)<0.04: annihilation correction, little effect on V_{td}/V_{ts}

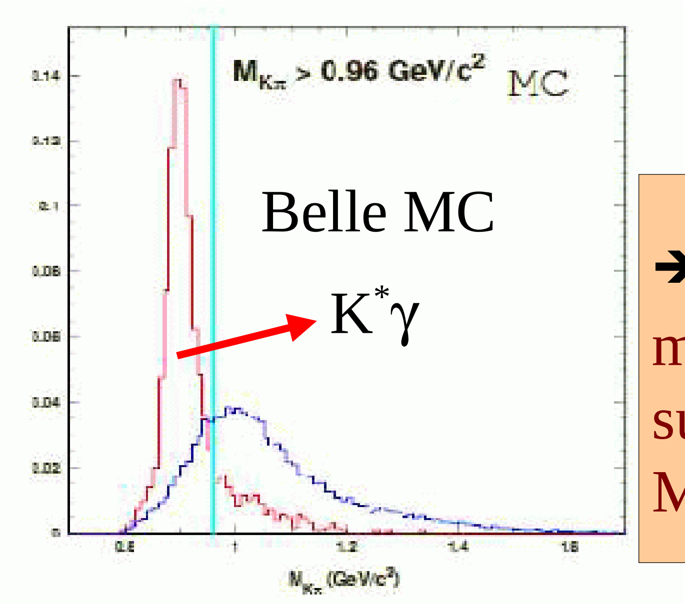
➔$\xi = F_{K^*}/F_\rho$ ratio of heavy to light FF

$\xi_{LQCD\&LCSR}$ (CKM2005) = 1.2 ± 0.1

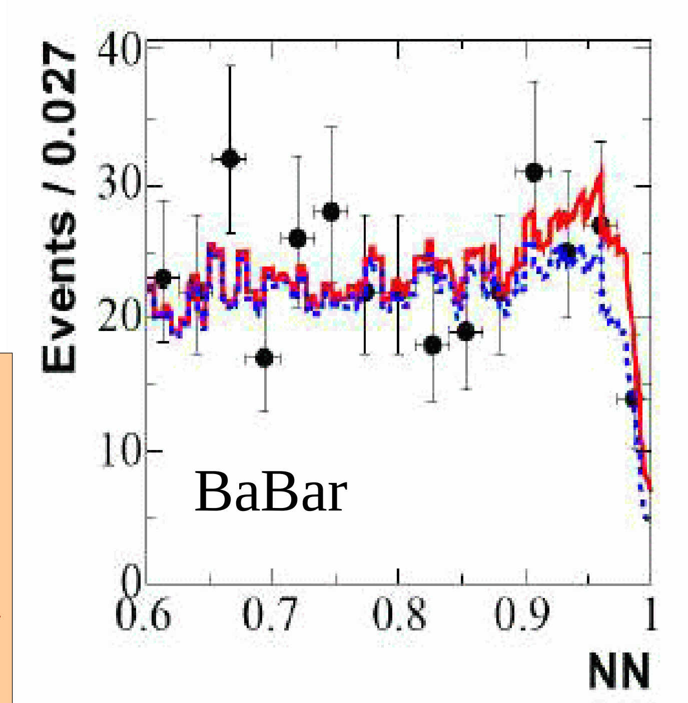
Search for $B \rightarrow \rho(\omega)\gamma$



- ➔ $B^+ \rightarrow \rho^+\gamma$, $B^0 \rightarrow \rho^0(\omega)\gamma$ & $K^*\gamma$ control sample
- ➔ Dominant BKG from continuum (ISR, π^0 (η) decays), suppressed by: event shape variables, B polar angle, flavor tagging & vertex separation combined in neural network or likelihood ratio



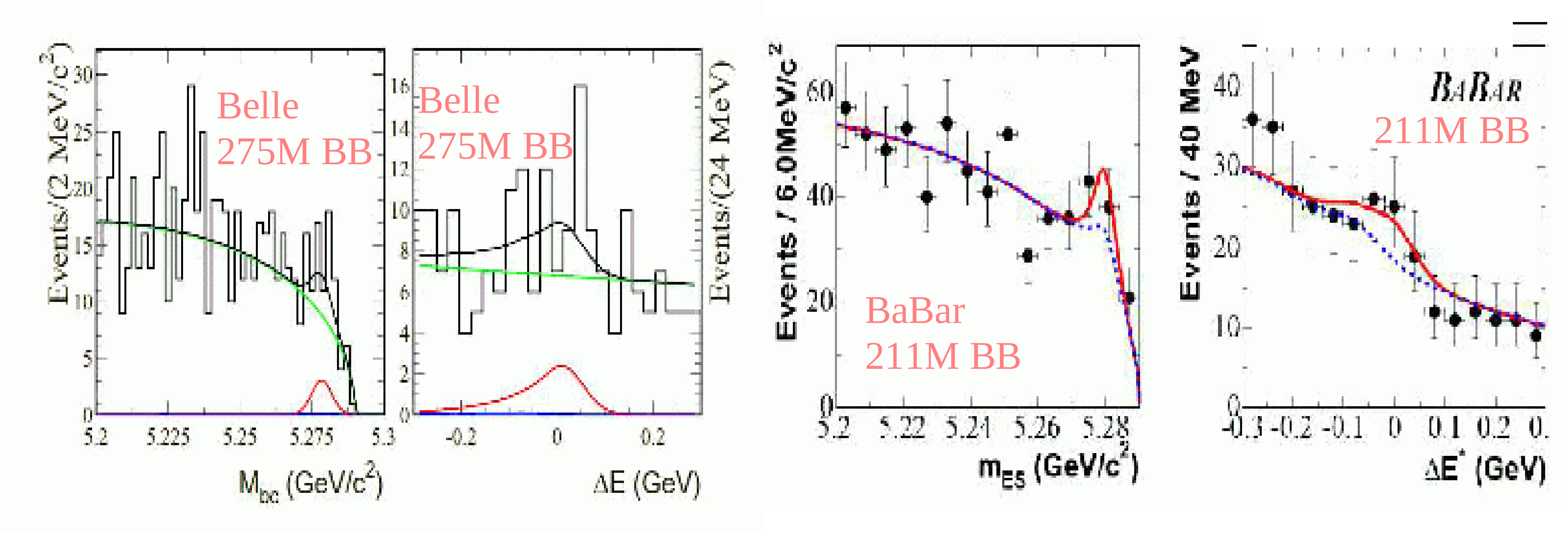
- ➔ $K^*\gamma$ BKG (K misidentified as π) suppressed with PID & $M(K\pi)$



Search for B→ρ(ω)γ

➔Unbinned fit to m_{ES}, ΔE

assuming isospin relation $BR(B^+ \to \rho^+\gamma) = 2(\tau B^+/\tau B^0)\, BR(B^0 \to \rho^0(\omega)\gamma)$

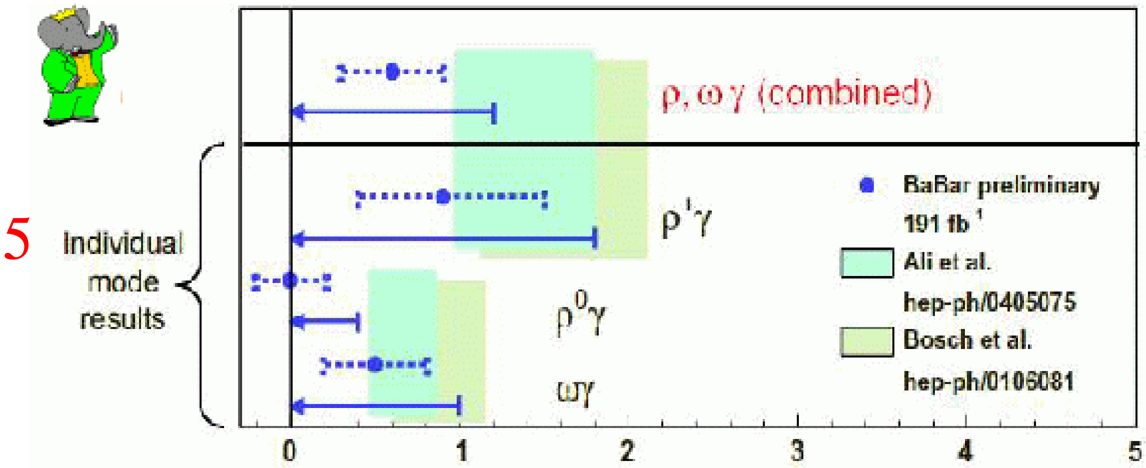


$BR(B^0 \to \rho^0(\omega)\gamma)$	$<1.4\times10^{-6}$ (90% CL)	$<1.2\times10^{-6}$ (90% CL)
Significance	1.9σ	2.1σ

[SM: $BR(B^0 \to \rho^0(\omega)\gamma) = (0.9\text{–}1.8) \times 10^{-6}$]

➔Systematics from BB modeling & signal ε

V_{td}/V_{ts} from Radiative Penguin: Summary



➔ Belle [hep−ex/0408137]:

$BR(B \to \rho(\omega)\gamma)/BR(B \to K^{*}\gamma) < 0.035$

$V_{td}/V_{ts} < 0.21$ at 90% CL

➔ BaBar [PRL 94, 011801]:

$BR(B \to \rho(\omega)\gamma)/BR(B \to K^{*}\gamma) < 0.029$;

$V_{td}/V_{ts} < 0.19$ at 90% CL

➔ Individual modes $\times 10^{6}$ (90%CL):

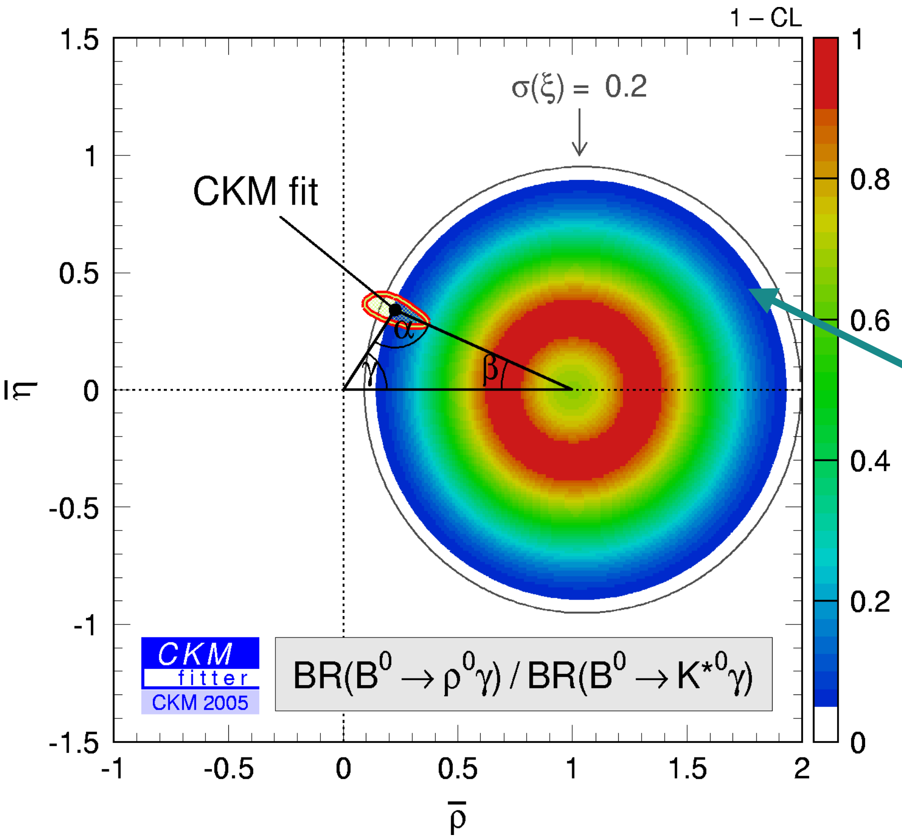
Mode	BaBar	Belle
$B^{+} \to \rho^{+}\gamma$	1.8	2.2
$B^{0} \to \rho^{0}\gamma$	0.4	0.8
$B^{0} \to \omega\gamma$	1.0	0.8

➔ Inclusive

$BR(b \to dg)/BR(b \to sg)$ from Super−B Factories? [10−20% accuracy at 10 ab^{-1}, theory error ~10%]

V_{td}/V_{ts} from Radiative Penguin: Summary

➔From BaBar & Belle $BR(B\to\rho(\omega)\gamma)/BR(B\to K^*\gamma)$

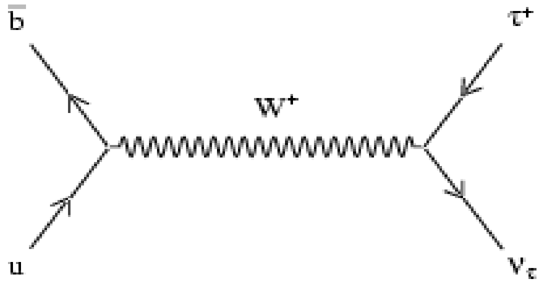


➔$\xi=F_{K*}/F_{\rho}$ ratio of heavy to light FF

$\xi_{LQCD\&LCSR}$ (CKM2005) = 1.2 ± 0.1

➔Limit from radiative penguin already meaningful!
➔Standalone constraint from B−Factories

V_{ub}/V_{td} from $B^+ \to \tau^+\nu_\tau$: BaBar Analyses



➔Sensitive to New Physics, provides clean measurement of F_B (given V_{ub})

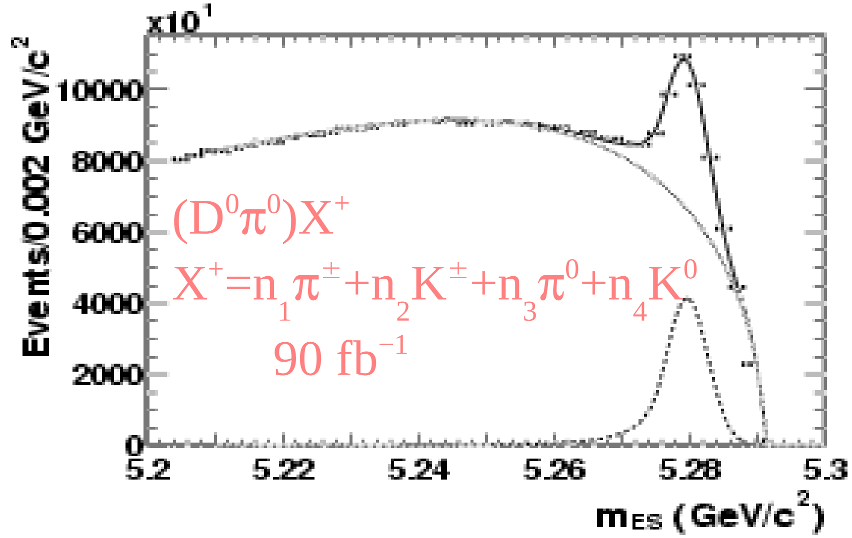
$$BR(B\to\tau\nu)=\frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1-\frac{m_\tau^2}{m_B^2}\right]^2 \tau_B F_{Bd}^2 |V_{ub}|^2$$

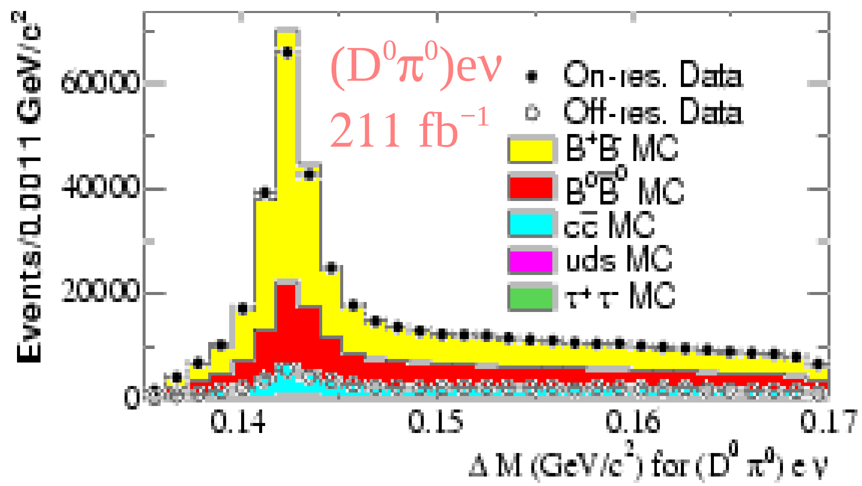
$$\Delta m_d=\frac{G_F^2}{6\pi^2} m_{Bd} \hat{B}_{Bd} F_{Bd}^2 \eta m_W^2 S_0(x_t) |V_{td}|^2$$

➔ V_{ub}/V_{td} from BR & Δm_d measurements (dependence on F_B drops out)

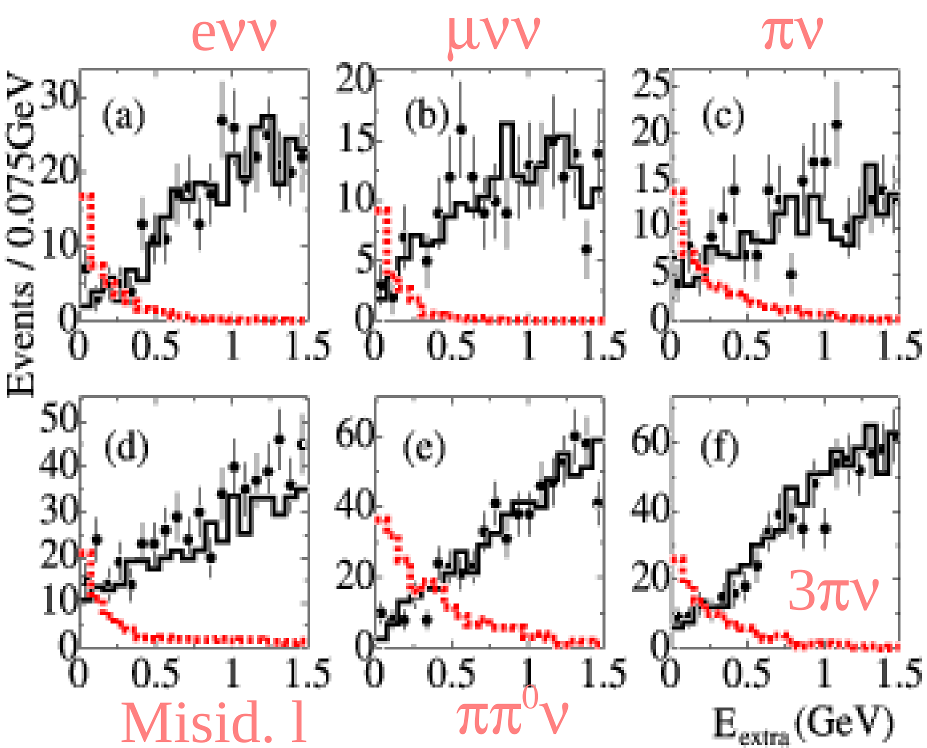
➔Standalone constraint from B−Factories

➔$B \to \tau^+\nu_\tau$ searched on the recoil of reconstructed hadronic $B^- \to D^{(*0)}X^-$ & semileptonic $D^{*0}l\nu$, $D^{*0} \to D^0\pi^0(\gamma)$ decays





$B^+ \rightarrow \tau^+\nu_\tau$: BaBar SL Tag Analysis



➔ τ reconstructed in several channels (81% of modes, ε_{SIG}~31%)

➔ BKG suppression exploiting missing mass, kinematical & topological variables

➔ Discriminant variable E_{extra}: residual neutral calorimeter energy

➔ $BR(B^+ \rightarrow \tau\nu_\tau) < 2.8\times10^{-4}$ (90% CL)

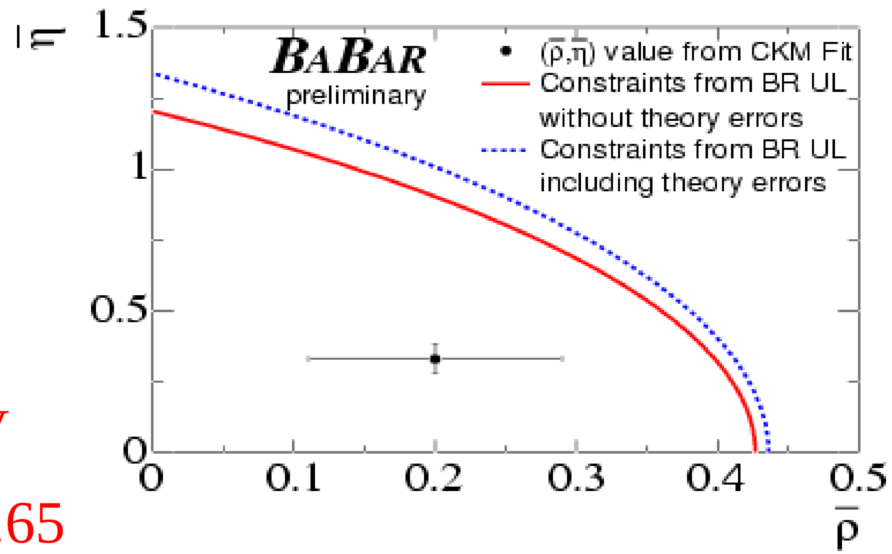
(hadronic tag: $BR(B^+ \rightarrow \tau\nu_\tau) < 4.2\times10^{-4}$)

[hep−ex/0407038]

➔ Systematics from efficiency & BKG subtraction

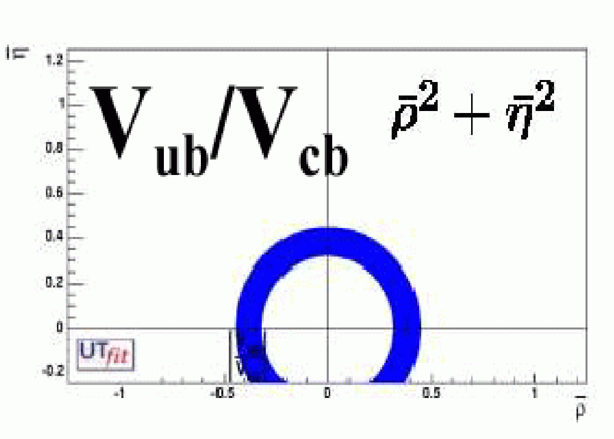
➔ Using world average V_{ub}: $F_B < 0.410$ GeV

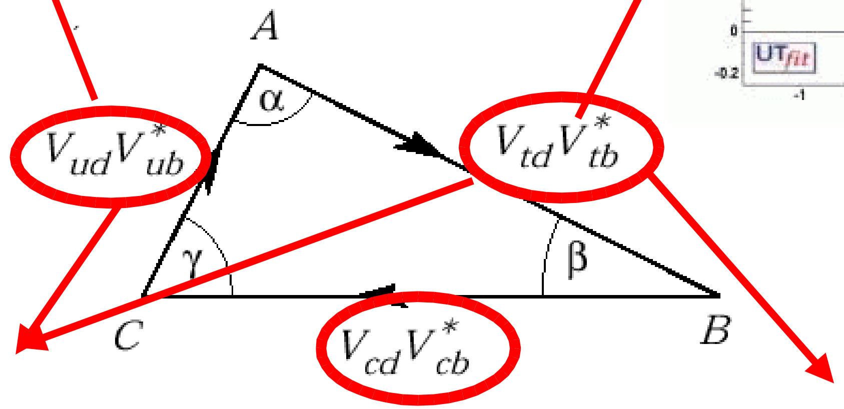
➔ Using world average Δm_d: $|V_{ub}|^2/|V_{td}|^2 < 0.65$

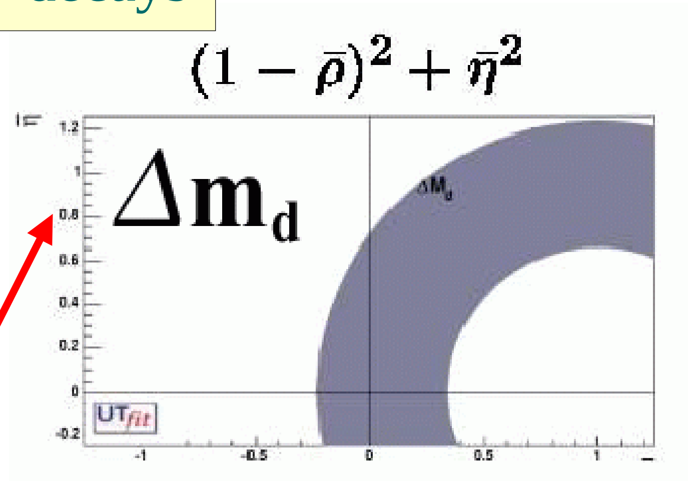


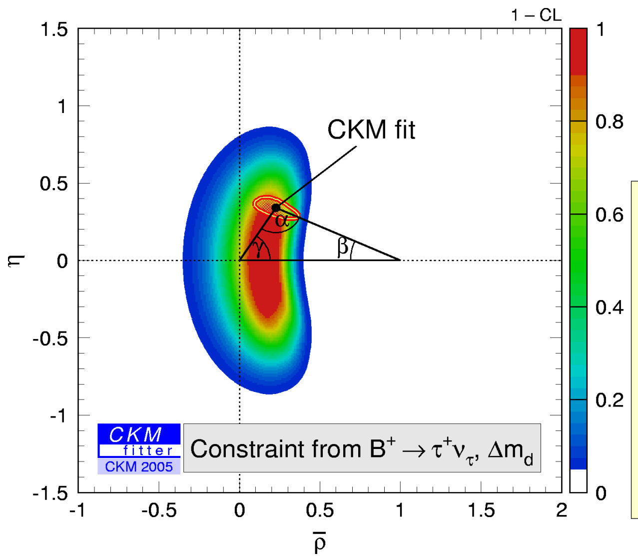
Conclusion: constraints in the (ρ, η) plane

➔ V_{ub}/V_{cb}, V_{td}/V_{ts} constrain sides of CKM triangle:
several measurements using exclusive & inclusive B decays





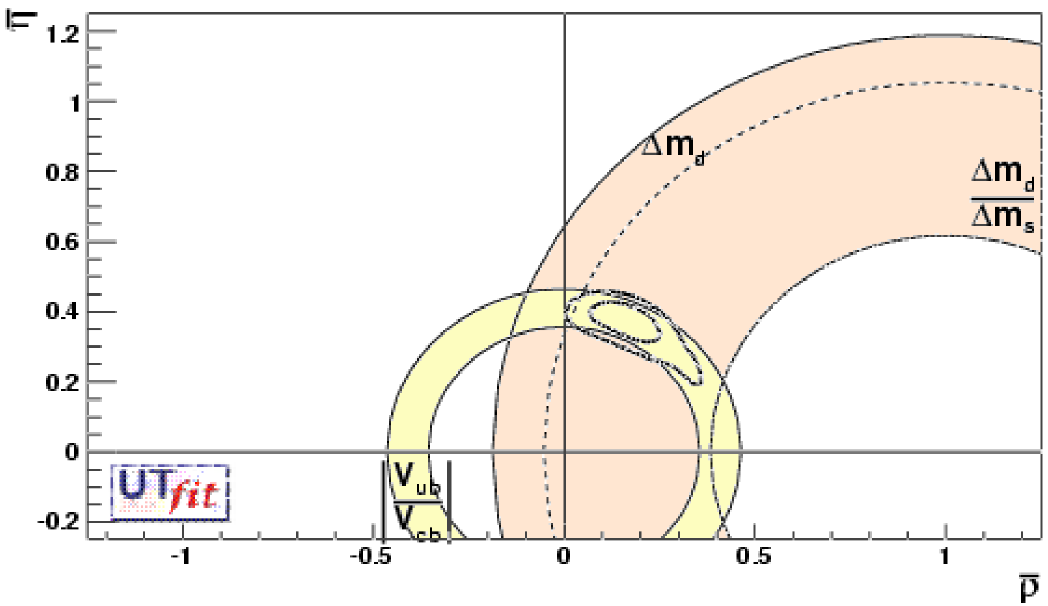




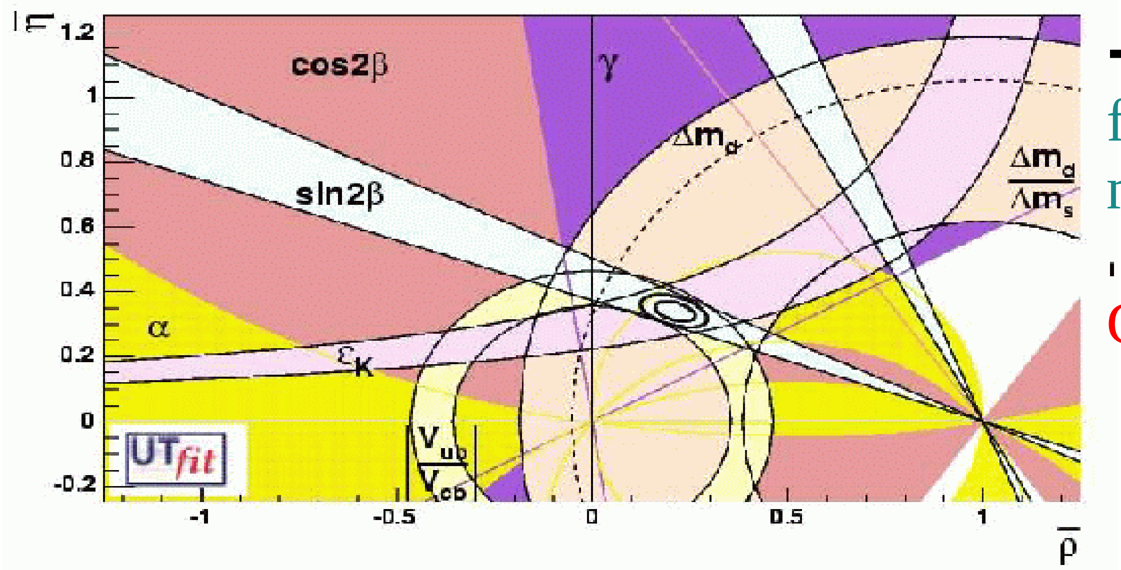
➔ $B^+ \to \tau\nu_\tau$ (V_{ub}/V_{td}) & Δm_d : removed F_B dependence

➔ $\rho\gamma/K^*\gamma$: still in discussion how to manage theoretical errors in the global fit

Conclusion: constraints in the (ρ, η) plane



➔Unitarity Triangle constraint from combined measurements of sides



➔Adding measurements of angles from B−Factories & K measurements:

Global Utfit results [CKM2005]:

$\rho = 0.207^{+0.035}_{-0.045}$

$\eta = 0.339^{+0.026}_{-0.021}$