Precision determinations of $|V_{cb}|$ and $|V_{ub}|$

Probing weak interactions and

CP violation in the quark sector

with semileptonic B decays

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Outline

- Importance of testing CKM picture of ~~CP~~
- B factories – the luminosity frontier
- HQET and OPE for heavy quarks

NEW $|V_{cb}|$ from inclusive decays ($b \to c\ell\nu$)

NEW $|V_{cb}|$ from exclusive decays ($B \to D^{*}\ell\nu$)

Soon $|V_{ub}|$ from inclusive decays ($b \to u\ell\nu$)

Soon $|V_{ub}|$ from exclusive decays ($B \to \pi\ell\nu$)

Weak interactions of quarks

- Historically fruitful area of research
  - τ / θ puzzle (1950s)
  - Parity violation (1956)
  - Flavour oscillations (1956 (K^0), 1987 (B^0))
  - CP violation (1964 (K^0), 2001 (B^0))
- The only verified mechanism for CP violation is the non-trivial phase in CKM matrix
- B factories allow precision studies of CKM
- Rare B decays offer window on new physics

CKM matrix

- The Wolfenstein++ parameterization is used here

Buras, Lautenbacher, Ostermaier, PRD 50 (1994) 3433.

$$
\begin{array}{cccc}
 & \text{d} & \text{s} & \text{b} \\
V_{CKM} = & \left(\begin{array}{c} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 \\ -\lambda+\frac{1}{2}A^2\lambda^5\left[1-2(\rho+i\eta)\right] \\ A\lambda^3\left[1-(\rho+i\eta)\left(1-\frac{1}{2}\lambda^2\right)\right] \end{array} \right. & \begin{array}{c} \lambda \\ 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4\left(1+4A^2\right) \\ -A\lambda^2+A\left(\frac{1}{2}-\rho-i\eta\right)\lambda^4 \end{array} & \left. \begin{array}{c} A\lambda^3(\rho-i\eta) \\ A\lambda^2 \\ 1-\frac{1}{2}A^2\lambda^4 \end{array} \right) \begin{array}{c} \text{u} \\ \text{c} \\ \text{t} \end{array}
\end{array}
$$

- shown here to $O(\lambda^5)$ where $\boldsymbol{\lambda} = \sin\theta_{12} = 0.22$
- V_{us}, V_{cb} and V_{ub} have simple forms by definition
- Free parameters $\boldsymbol{A}$, $\boldsymbol{\rho}$ and $\boldsymbol{\eta}$ are order unity

A Unitarity Triangle

λ, A, $\overline{\rho}$ and $\overline{\eta}$

At the 1% level: $|V_{us}|$

$$\lambda = |V_{us}| = \sin\theta_c$$

$$\lambda = 0.2205 \pm 0.0018$$

At the 2% level: $|V_{cb}|$

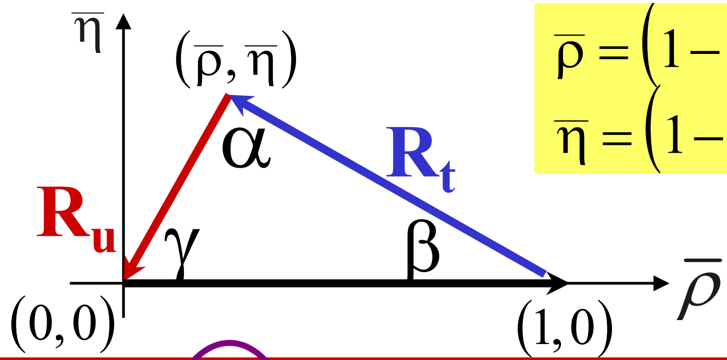
$$A = |V_{cb}| / \lambda^2$$

$$A = 0.84 \pm 0.02$$

$|V_{ub}|$ and $|V_{td}|$

$\rightarrow \overline{\rho}\text{-}\overline{\eta}$ plane

Unitarity: $1 + R_t + R_u = 0$



$$\overline{\rho} = \left(1 - \lambda^2/2\right)\rho$$

$$\overline{\eta} = \left(1 - \lambda^2/2\right)\eta$$

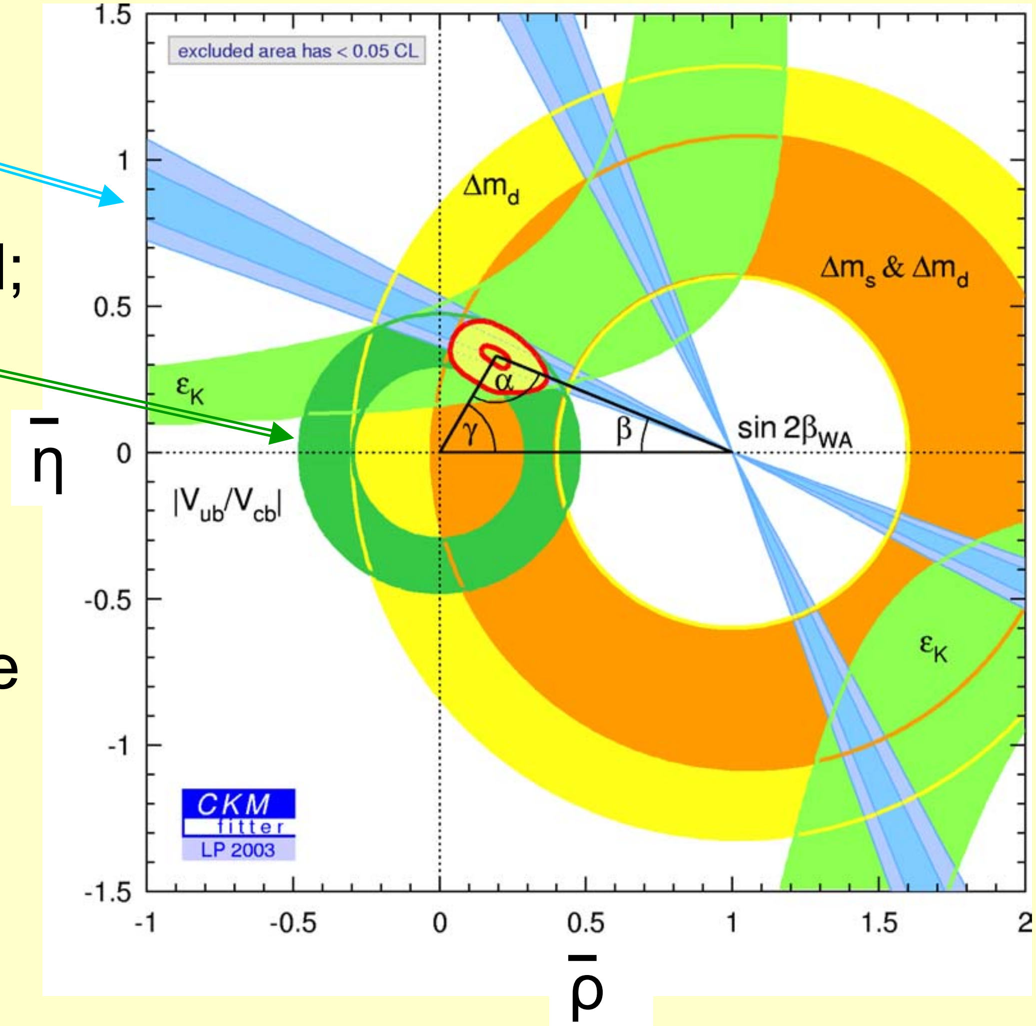
$$R_u = \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \approx -\sqrt{\overline{\rho}^2 + \overline{\eta}^2}\; e^{i\gamma}$$

$$R_t = \frac{V_{td} V_{tb}^*}{V_{cd} V_{cb}^*} \approx -\sqrt{(1-\overline{\rho})^2 + \overline{\eta}^2}\; e^{-i\beta}$$

$$\gamma = \arg V_{ub}^*, \quad \alpha = \pi - \gamma - \beta$$

Constraints on CKM

- Good precision (and improving) on sin2β
- $|V_{ub}|/|V_{cb}|$ is powerful; improvements will have impact
- These two measurements alone could show a violation of unitarity

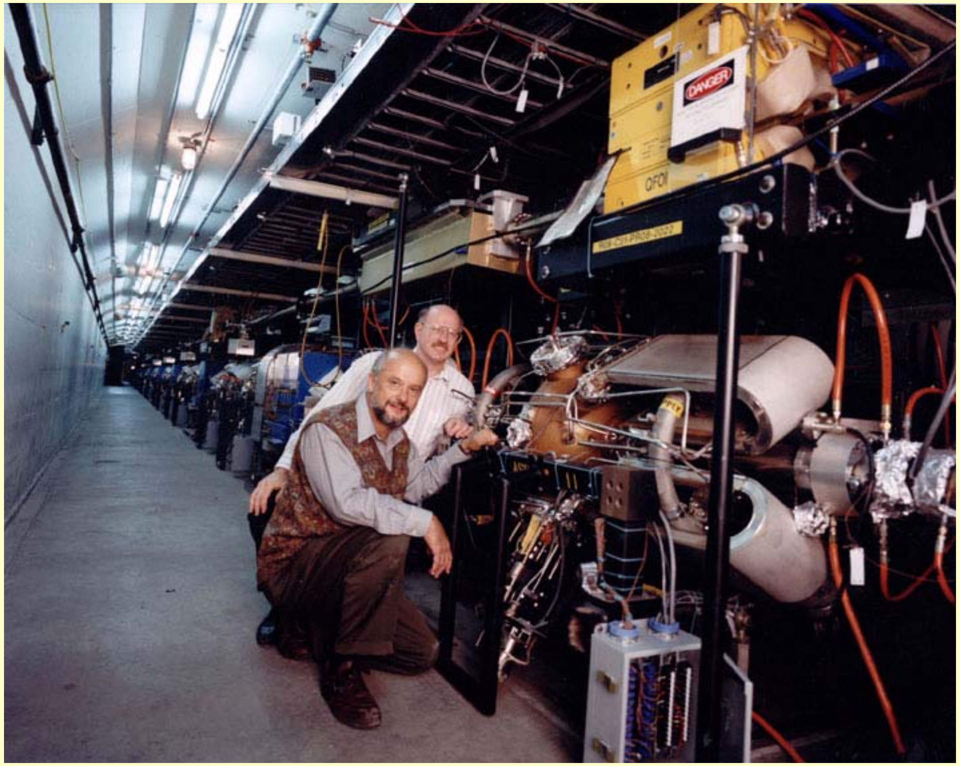


B factories

- PEP-II/BaBar and KEK-B/Belle
  - Asymmetric e^+e^- colliders, $\sqrt{s}$ = 10.58 GeV
  - Approved in 1994, first data in 1999
  - CP violation observed in 2001
  - Luminosity records continue to be set
- *Two* big success stories
  - Focus of *this talk* is on BaBar
  - Belle results will be mentioned where relevant

PEP-II and KEK-B

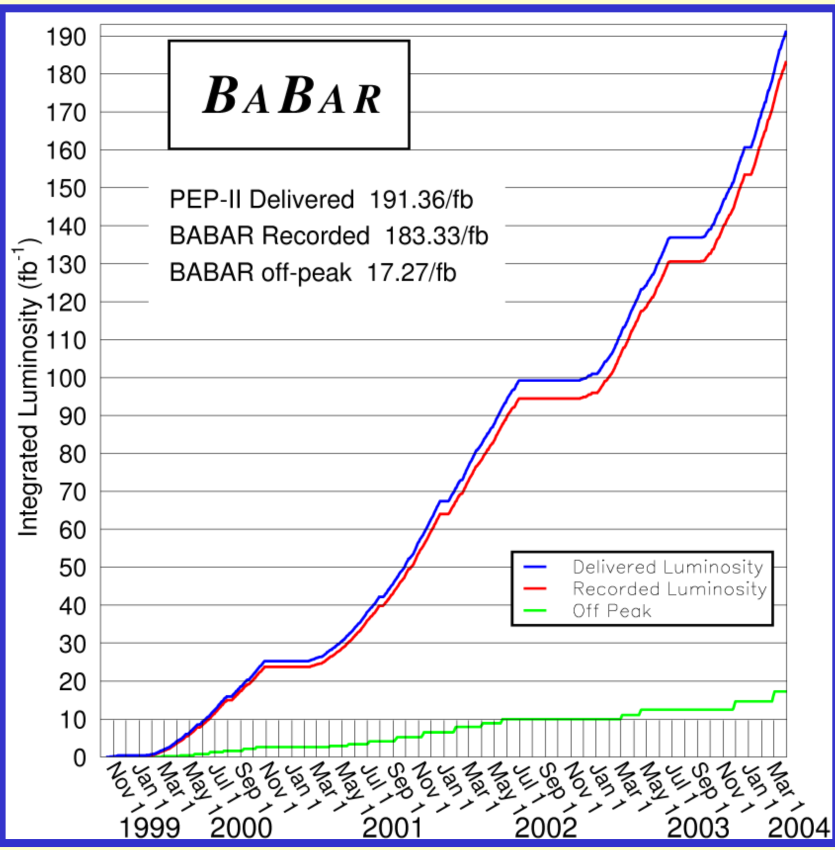
Asymmetric e^+e^- colliders

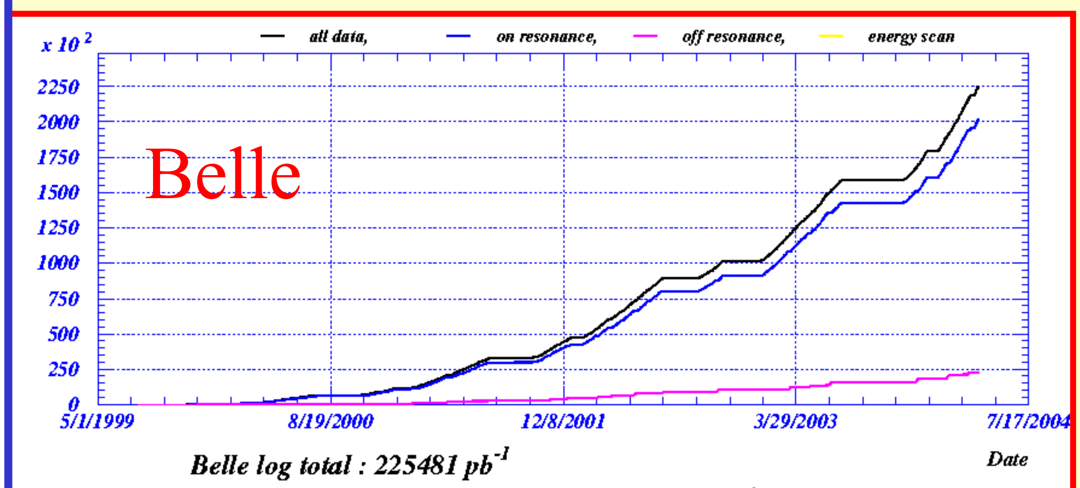


Luminosity (as of April 7, 2004)

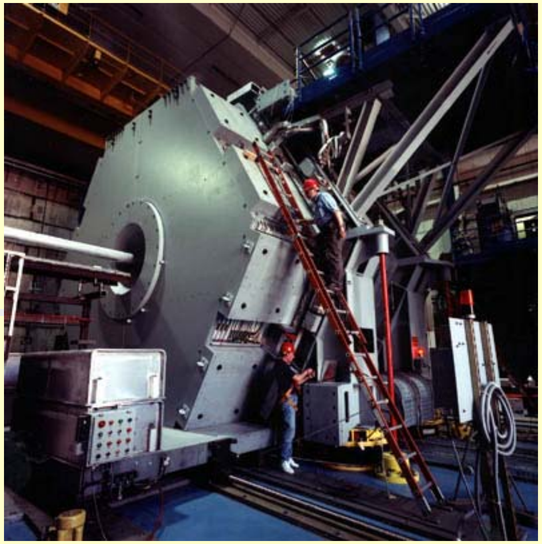
Both B factories are running extremely well:

	Belle	BaBar
$\mathcal{L}_{max}$ ($10^{33}/cm^2/s$)	12.0	8.3
best day (pb^{-1})	880	622
total (fb^{-1})	222	184



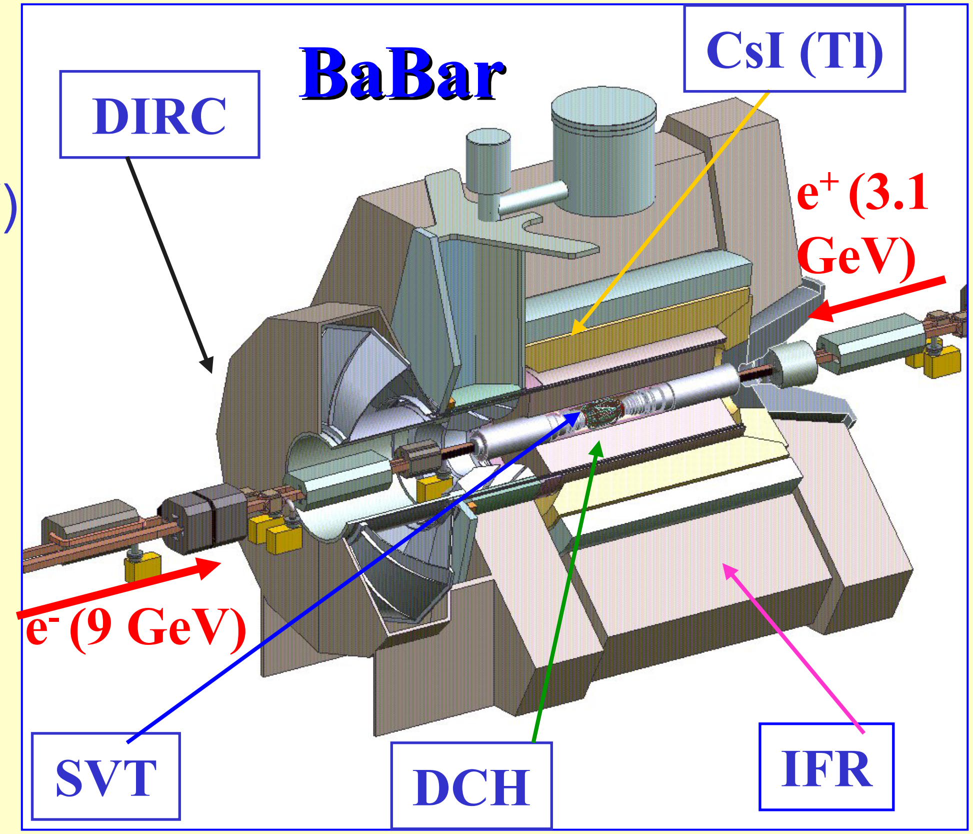


BaBar detector



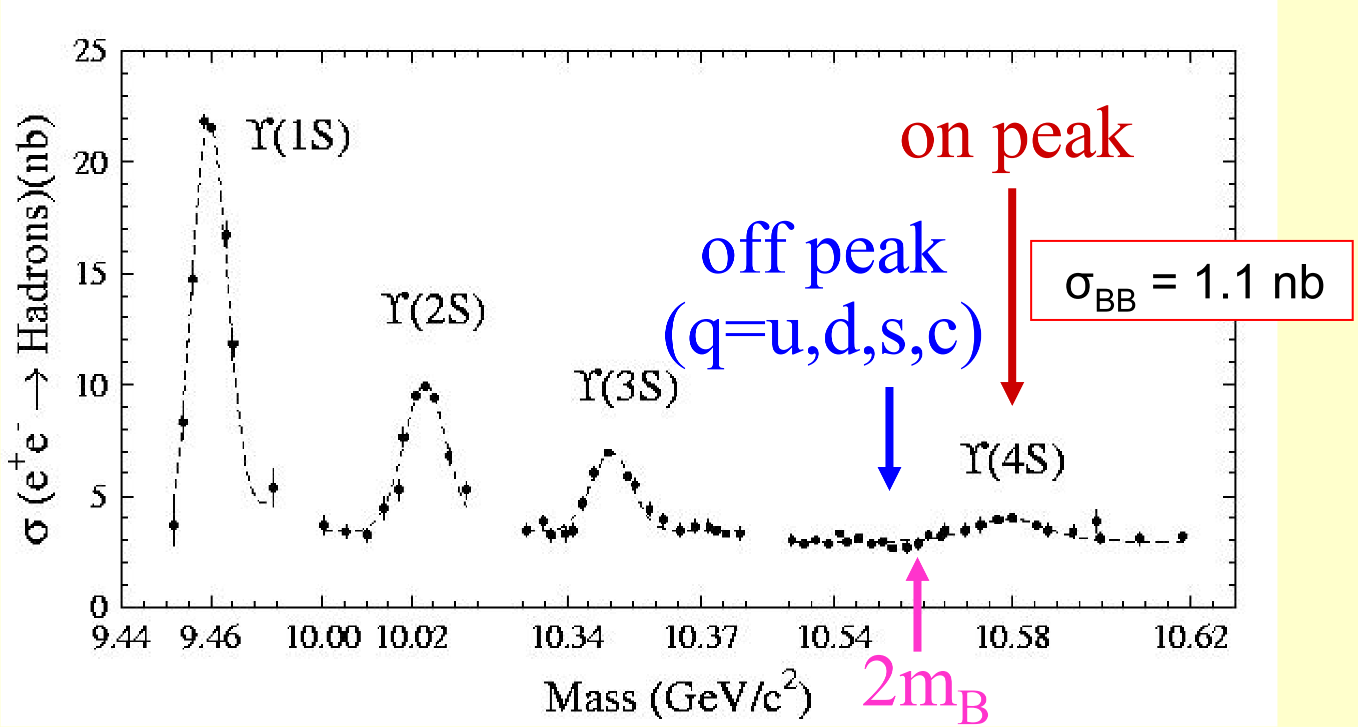
- General purpose collider detector
- F-B asymmetric due to boost of CM
- Crossings every *n**4.2 ns
- Standalone 5-layer Si tracker for low-p_T (<0.1 GeV)
- Low-mass drift chamber with He-isobutane gas
- Unique ultra-thin imaging Cherenkov detector
- CsI(Tl) crystal calorimeter
- Instrumented flux return

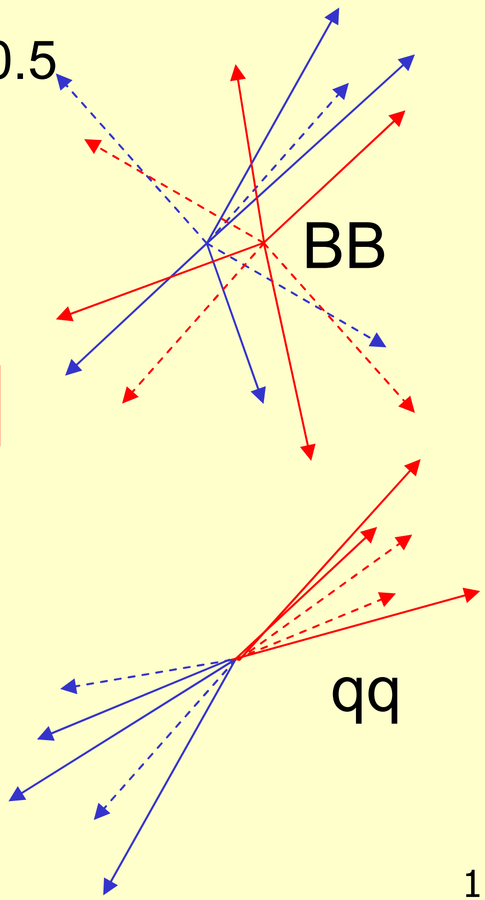
increasing radius



Y(4S) experiments

- $e^+e^- \rightarrow Y(4S) \rightarrow B^+B^-$ and B^0B^0 ~ 50% each
- B nearly at rest ($\beta\gamma$ ~ 0.06) in 4S frame → overlapping decays
- Asymmetric beam energies boost into lab: $(\beta\gamma)_{4S}$ ~0.5





Understanding B decay

- b quark weak decay is complicated by QCD
- Both perturbative (m_b) and non-perturbative (Λ_{QCD}) effects
- Tools:
  - Heavy quark symmetry
    - Heavy Quark Effective Theory
    - Operator Product Expansion (HQE effective field theory)
  - Lattice QCD

Heavy Quark Symmetry

- Heavy quark is "invisible" to gluon probes with de Broglie wavelength $\lambda_g >> 1/m_Q$
  - HQ spin and mass (flavour) are good symmetries as $m_Q / \Lambda_{QCD} \rightarrow \infty$
  - Departures from HQ symmetry can be expressed as $(\Lambda_{QCD} / m_Q)^n$ corrections
  - In several important cases, the $(\Lambda_{QCD} / m_Q)^1$ term vanishes (Luke's theorem)

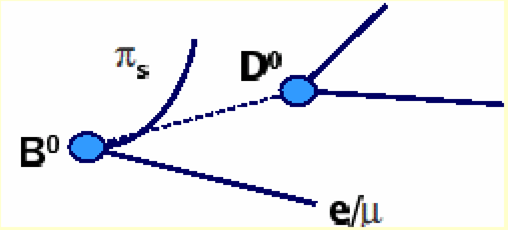
$|V_{cb}|$ from exclusive $b \to c\ell\nu$ decays:

$$B^0 \to D^{*+}\ell\nu$$

Heavy Quark Effective Theory

- Based on HQ symmetry for $Q \to Q'$
  - Applies to $b \to c$ transitions, e.g. $B \to D^* \ell \nu$
  - Departures from HQ limit ~ $(\Lambda_{QCD} / m_c)^k$
- All $B \to D^{(*)} \ell \nu$ transitions are governed by *one form factor* (the Isgur-Wise function $\xi(w)$, $w = v_B \cdot v_{D^*} \geq 1$) in the HQ limit
  - In HQ limit, $\mathcal{F}(1) = \xi(1) = 1$ (D^* at rest in B rest frame)
  - Extract $\mathcal{F}(1)|V_{cb}|$ from rate $d\Gamma/dw$ ($w \to 1$)
  - Calculate $\mathcal{F}(1)$ using non-perturbative methods

$B \rightarrow D^{*}\ell\nu$

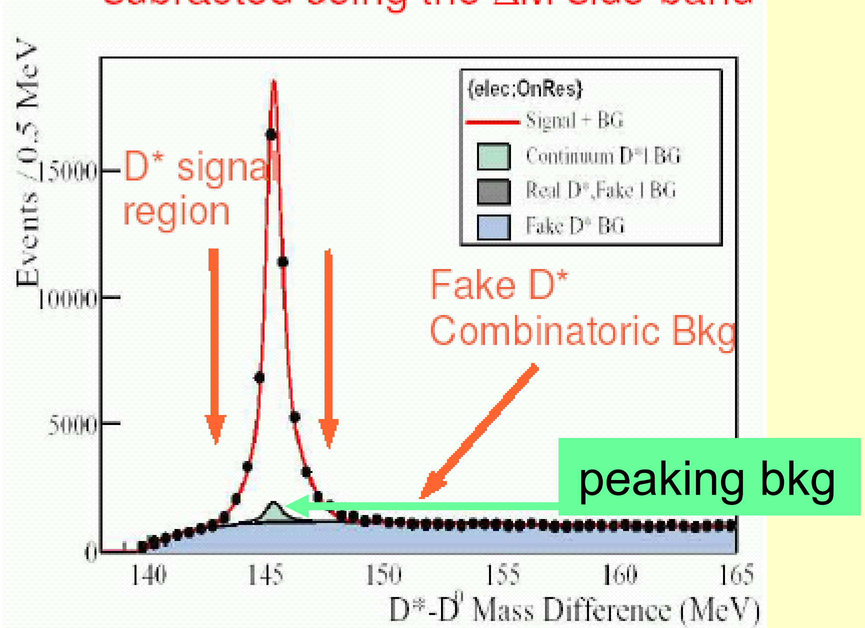


Sample of $B^0 \rightarrow D^{*-}l^+\nu$

- $D^{*-} \rightarrow D^0\pi^-_{soft}$
- $D^0 \rightarrow K\pi, K3\pi, K\pi\pi^0$
- High energy lepton: e & μ $P_l > 1.2$ GeV/c

*** Combinatorial background:**

subracted using the ΔM side band



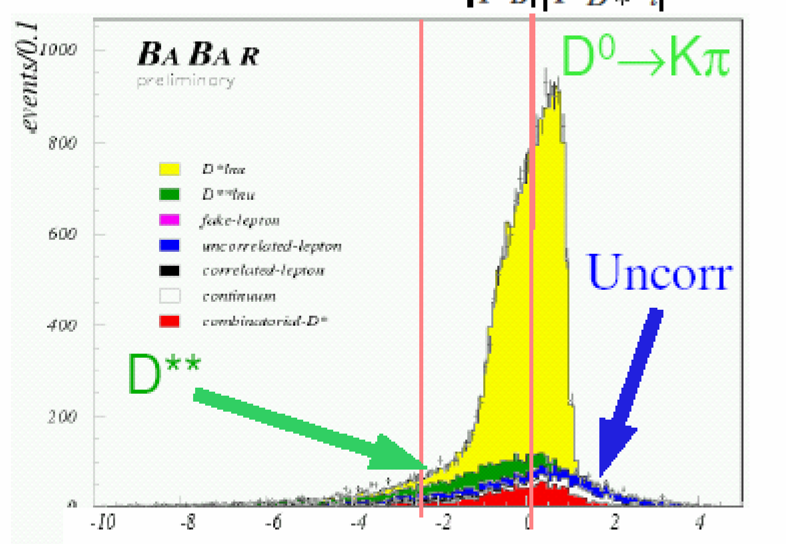
Separate fit in each w bin

*** $B_1 \rightarrow D^*X$, $B_2 \rightarrow lY$** (uncorrelated)

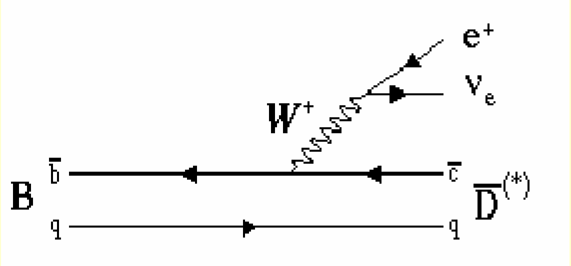
*** $B \rightarrow D^*Xl\nu$** (D** background)

separated fitting **$\cos\theta_{B-D^*l}$**

$$\cos\theta_{B,D^*l} \equiv \frac{2E_B E_{D^*l} - m_B^2 - m_{D^*l}^2}{2|\overline{p}_B||\overline{p}_{D^*l}|}$$



$B \to D^* \ell \nu$



- Measure differential decay rate (w = D^* boost in B frame [1-1.5])

$$\frac{d\Gamma\left(B \to D^* \ell \nu\right)}{dw} = \frac{G_F^2}{48\pi^3} \mathcal{G}(w) \left|V_{cb}\right|^2 \left(\mathcal{F}(w)\right)^2$$

extrapolate to w=1

- In HQ limit $\mathcal{F}$(w) → ξ(w). In HQET parameterize as

expansion in (1-w)

$$\mathcal{F}(w) = \mathcal{F}(1)\left(1 + \rho_{\mathcal{F}}^2 (1-w) + c(1-w)^2 + \ldots\right) \quad \text{or}$$

$$\mathcal{F}^2(w) = \frac{\mathcal{A}_1^2(w)}{1 + \frac{4w}{1+w}\frac{1-2wr+r^2}{(1-r)^2}} \left\{ 2\frac{1-2wr+r^2}{(1-r)^2}\left[1 + \tfrac{w-1}{w+1} R_1^2(w)\right] + \left[1 + \tfrac{w-1}{1-r}\left(1 - R_2(w)\right)\right]^2 \right\} \quad \text{with}$$

$$R_1(w) \propto \frac{V(w)}{A_1(w)} \quad \text{and} \quad R_2(w) \propto \frac{A_2(w)}{A_1(w)} \quad \text{and} \quad r = \frac{m_{D^*}}{m_{B^0}}$$

$$\mathcal{A}_1(w) = \mathcal{A}_1(1)\left[1 - 8\rho_{\mathcal{A}_1}^2 z + (53\rho_{\mathcal{A}_1}^2 - 15)z^2 - (231\rho_{\mathcal{A}_1}^2 - 91)z^3\right] \quad \text{with } z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

expansion in z

$B \to D^* \ell \nu$ (preliminary results)

$$\frac{dN}{dw} = \varepsilon(w) \frac{dB(\mathrm{B}^0 \to \mathrm{D}^* \ell \nu)}{dw}$$

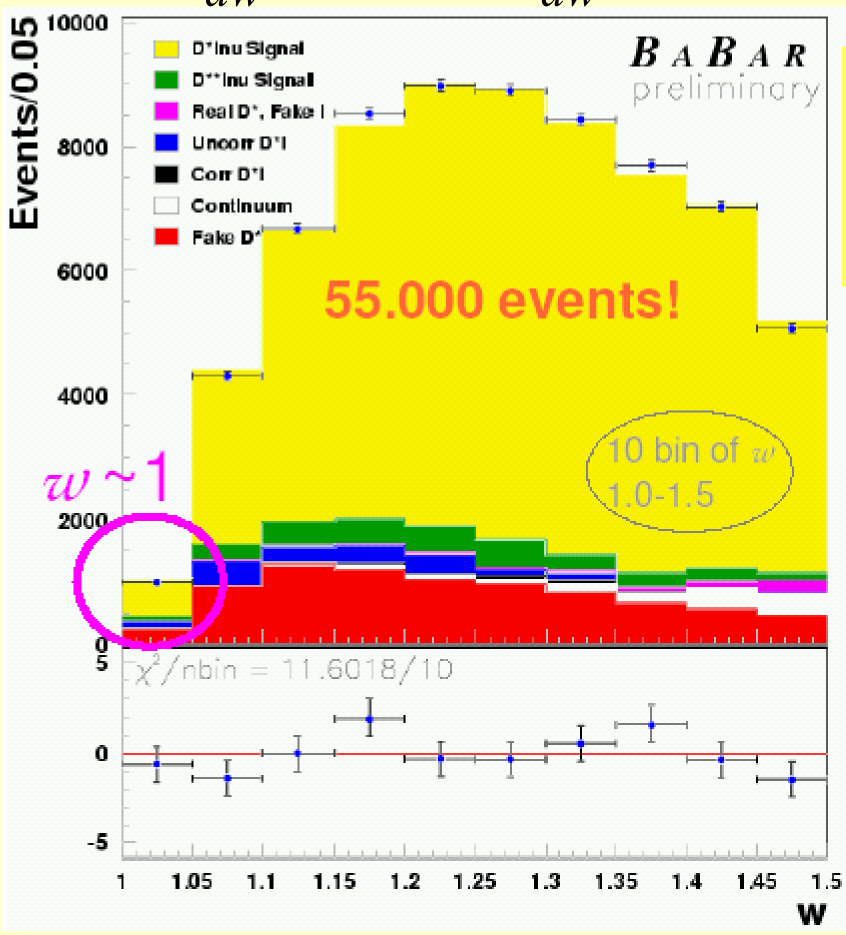
- High statistics sample
- w resolution ~ 0.04

$\mathcal{F}(1)|V_{cb}| = (34.03 \pm 0.24_{stat} \pm 1.31_{syst}) \times 10^{-3}$
$\rho^2 = 1.23 \pm 0.02_{stat} \pm 0.28_{syst}$
$Br(B^0 \to D^* l \nu) = (4.69 \pm 0.02_{stat} \pm 0.24_{syst})\%$

- Main uncertainties from FF ratios R_1 and R_2, extrapolation to w=1, D^{**} composition, slow π^+ efficiency
- Using $\mathcal{F}(1) = 0.92 \pm 0.03$ (from LQCD[1])

$|V_{cb}| = (37.27 \pm 0.26_{stat} \pm 1.43_{syst}{}^{+1.50}_{-1.20}) \times 10^{-3}$

[1]S. Hashimoto *et al.*, PRD **66** (2002) 014503



$|V_{cb}|$ from inclusive $b \to c\ell\nu$ decays

$$B \to X_c \ell \nu$$

OPE for $b \to c\ell\nu$ transitions

- $b \to c\ell\nu$ described by OPE in $(1/m_b)^n$ and α_s^k

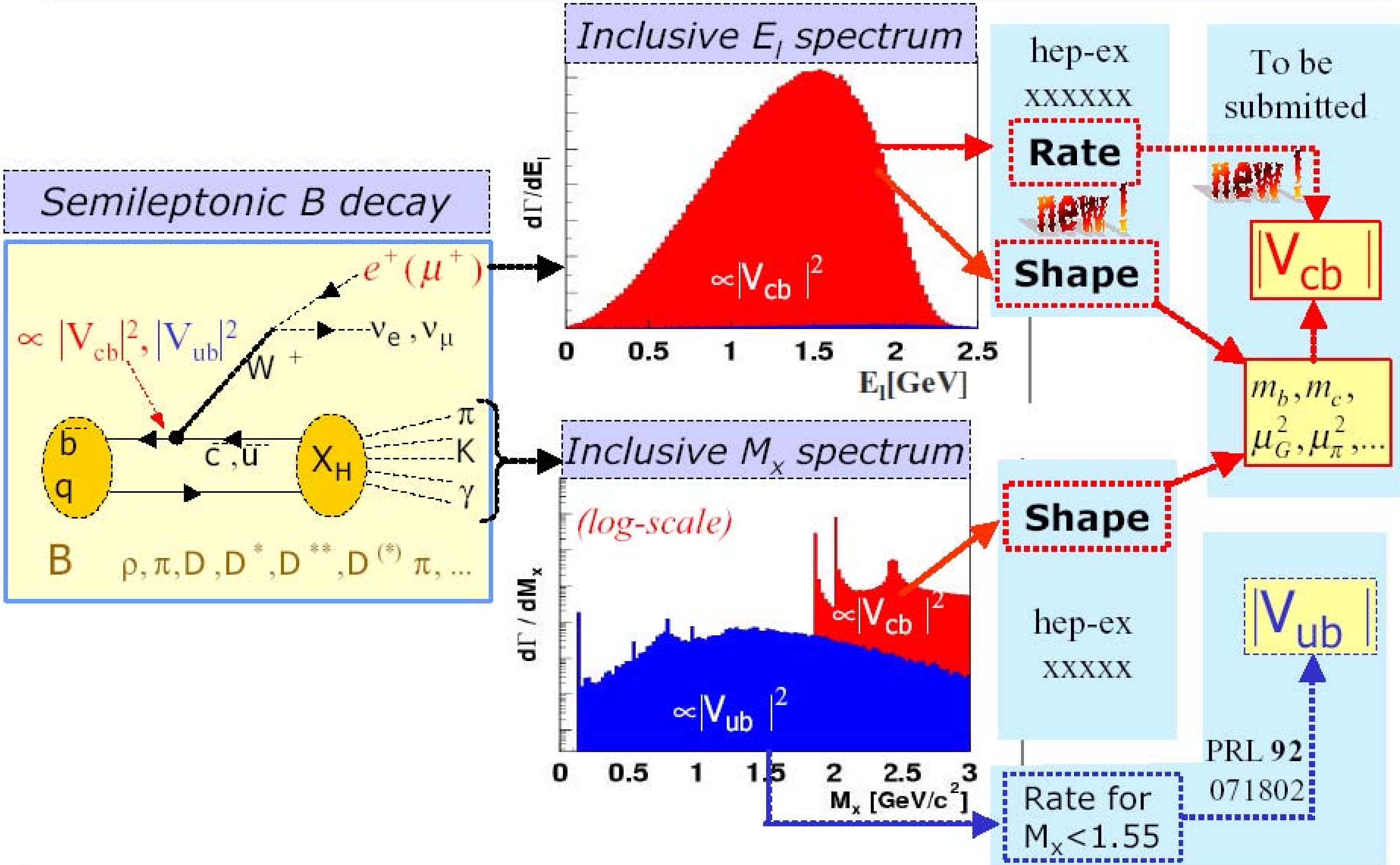
$$\Gamma(B \to X_c l \nu) = 1.014 \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \left[z_0(r)\left[1 + A_3^{pert}(r,\mu)\right]\left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}\right) - (1 + A_5^{pert}(r,\mu))2(1-r)^4 \frac{\mu_G^2}{m_b^2} + O\left(\frac{1}{m_b^3}\right)\right]$$

μ=1 GeV/c, scale which separates effects from long- and short-distance dynamics

$r = m_b/m_c$, z_0 = tree-level phase space factor , A^{pert} = pert. corrections (α_s , $\alpha_s^2\beta_0$)

  - non-perturbative parameters arise at each order:
    - Λ ($=m_B - m_b$)
    - μ_π^2 (aka λ_1), μ_G^2 (aka λ_2) at ($1/m_b^2$)
    - $\rho_{1\text{-}2}$, $\mathcal{T}_{1\text{-}4}$ at ($1/m_b^3$) …
  - parton-hadron duality assumed
- predicts many observables → testable

The Big Picture



Spectral moments: $\langle M_X^k \rangle$, $\langle E_e^k \rangle$

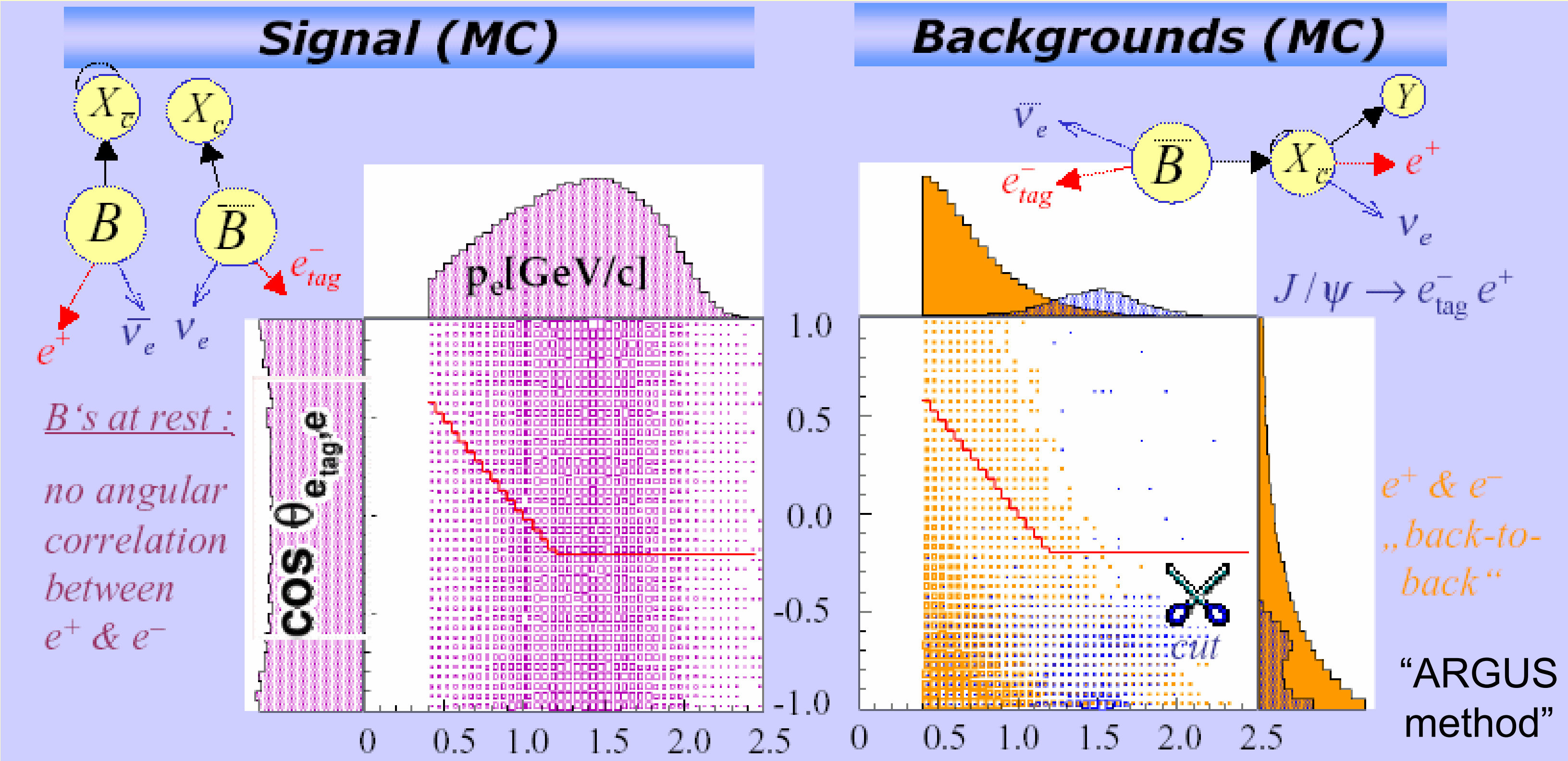
- Measure hadronic mass and lepton energy moments (in presence of minimum lepton energy cut)
- Compare with OPE calculation

Calculations available to $O\left(m_B^{-3}\right)$ and $O\left(\alpha_S^k\right)$, $k=1$ or 2

- Applying OPE calculations to real hadrons (duality) requires summing over a “large enough” phase space
- Spectral *moments* should be insensitive to duality
- A complete set of calculations is available in one renormalization scheme (soon to come in a second scheme)

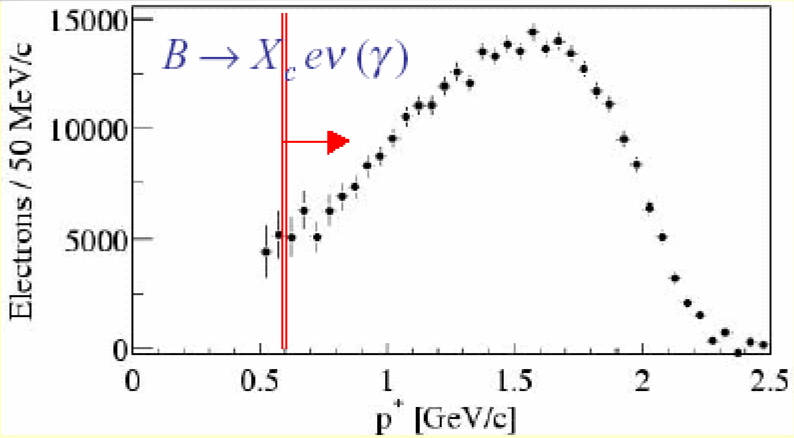
Electron spectrum measurement

- Exploit angular correlations in di-electron events
- Extract partial BF and moments, compare with theory

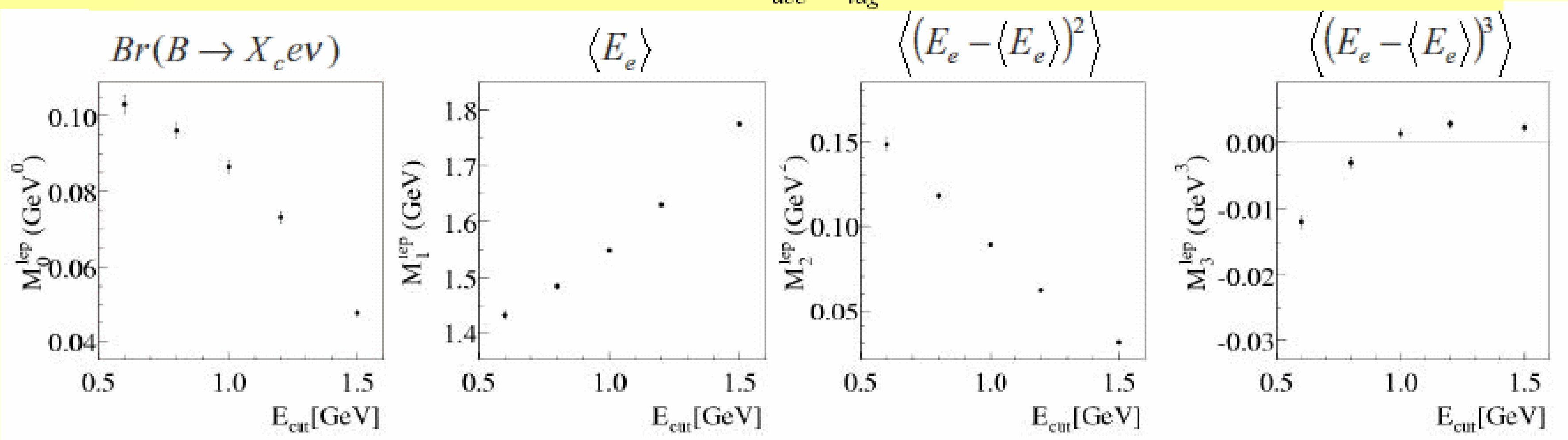


Electron energy moments

- Correct for BB mixing, b→ueν, backgrounds, Bremsstrahlung, QED radiation, elec id and misid...
- Extract 0th – 3rd moments vs $E_{e,cut}$

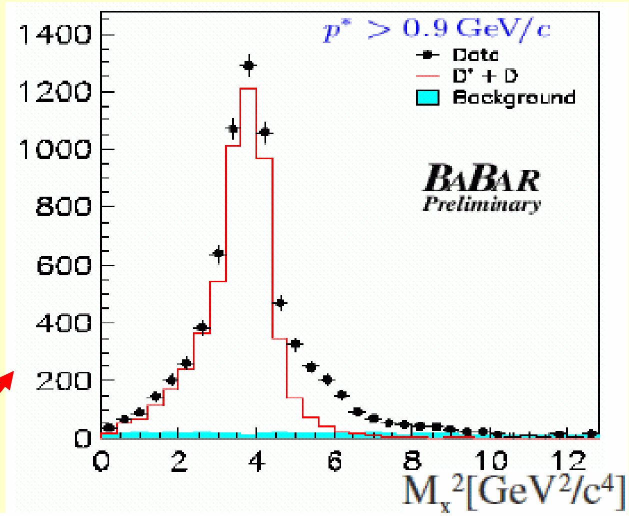


partial BF: $$Br(B \to Xe\nu(\gamma), E_e > 0.6\ GeV) = \frac{N_{b\to xe\nu}(E_e > 0.6 GeV)}{\varepsilon_{acc}\, N_{tag}} = (10.36 \pm 0.06_{stat} \pm 0.23_{sys})\%$$

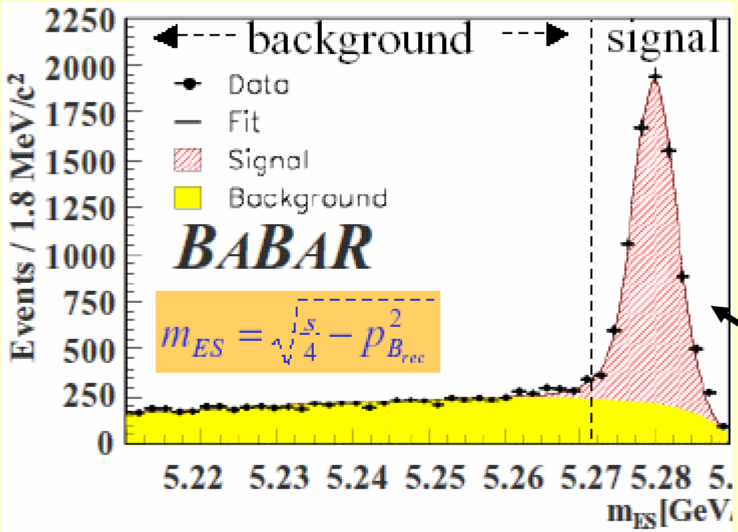


Measuring M_X in $b \to c\ell\nu$ decays

- Analysis strategy: fully reconstruct one B and study semileptonic decays of the recoiling B
  - Require $E_{miss} \approx |p_{miss}|$
  - kinematic constraints → fit for better m_X resolution (σ~0.35 GeV)
  - B-factory statistics make it possible

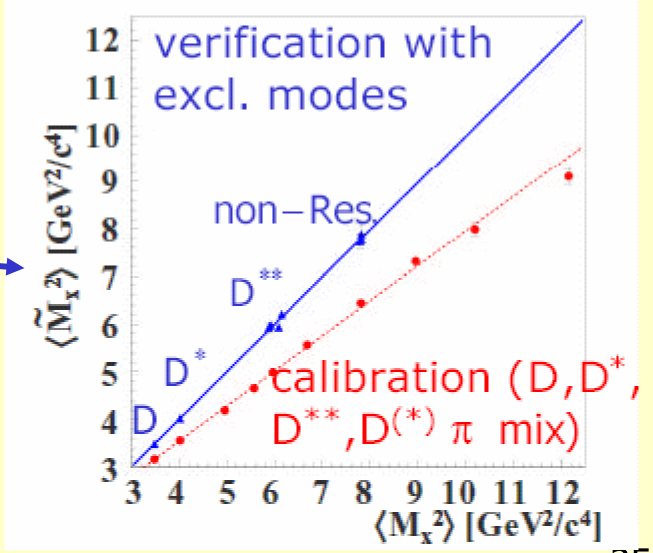


Recoil M_X^2



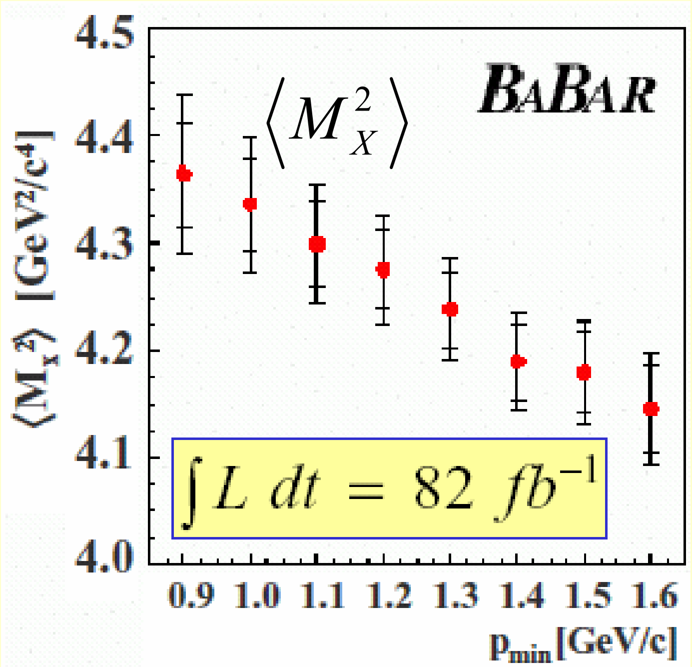
M_x calibration curve, applied event-by-event

Fully reconstructed



Hadronic mass moments

- Method validated on data using partially-reconstructed $D^*\ell\nu$ decays (π_s-ℓ correlations)
- Extract $\langle M_X^k \rangle$, k=1..4 as a function of $E_{e,cut}$
- Main systematic uncertainties:
  - non $b \to c\ell\nu$ background
  - simulation of track and neutral reconstruction
  - modeling of QED radiation
  - B-reco sideband subtraction



Fit to moments

- Fit E_e and M_X moments vs. E_0 to set of parameters:
  - $|V_{cb}|$, $\mathcal{B}(b \to c\ell\nu)$, m_b, m_c, μ_π^2, μ_G^2, ρ_D^3, ρ_{LS}^3
  - 8 unkowns, 25-35 observables (with reasonable correlations)

➢ $|V_{cb}|$ „master" formula : $|V_{cb}|^2 = Br(B \to X_c e\nu)/\tau_B \; f_\Gamma^\ell(E_0, m_b, m_c, \mu_G^2, \mu_\pi^2, \rho_{LS}^3, \rho_D^3)$

➢ $Br(B \to X_c e\nu, E_l > E_0)$: $M_0^\ell(E_0)/Br(B \to X_c e\nu) = f_0^\ell(E_0, m_b, m_c, \mu_G^2, \mu_\pi^2, \rho_{LS}^3, \rho_D^3)$

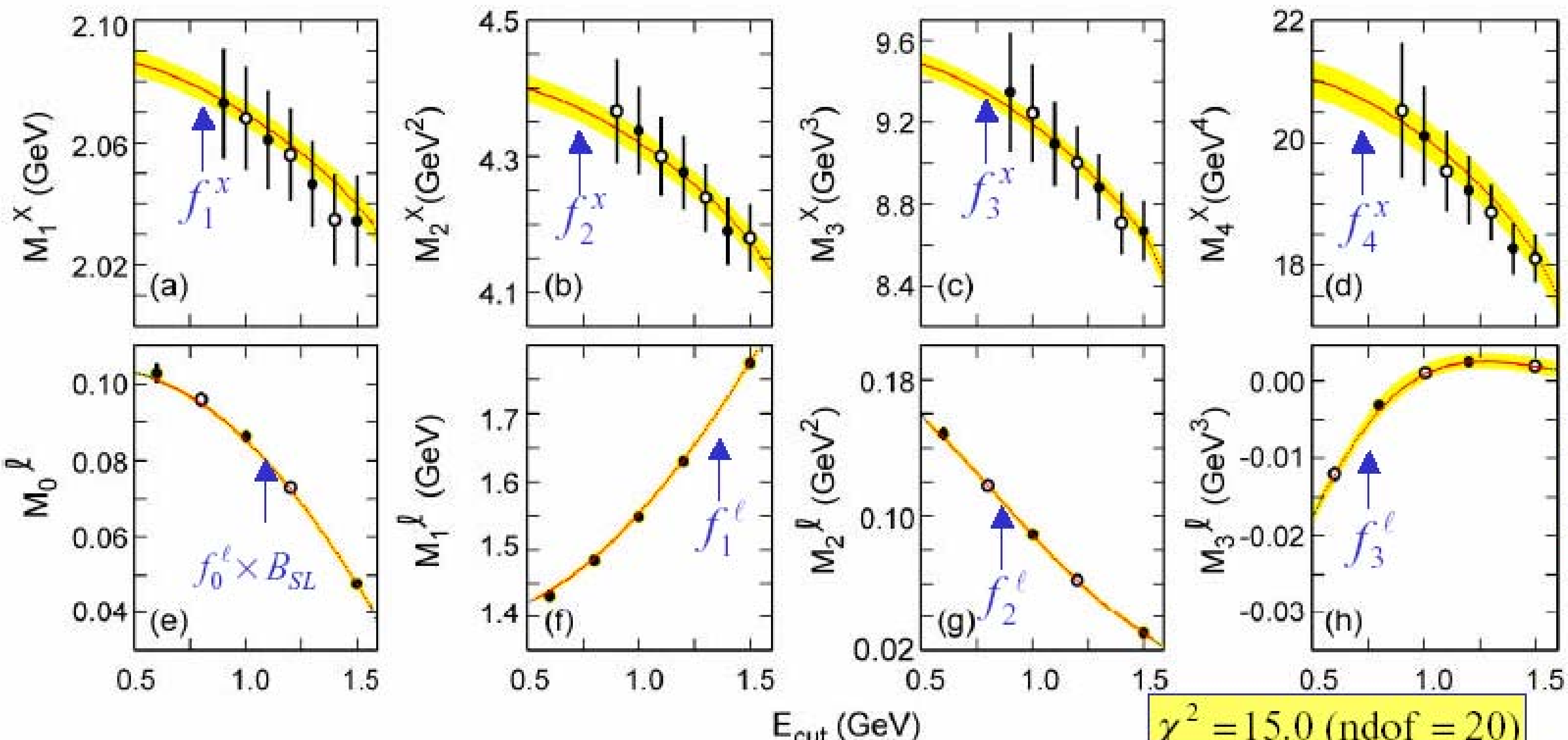
➢ i-th central E_l moment for $E_l > E_0$: $M_i^\ell(E_0) = f_i^\ell(E_0, m_b, m_c, \mu_G^2, \mu_\pi^2, \rho_{LS}^3, \rho_D^3)\; (i = 1..3)$

➢ i-th M_x moment and $E_l > E_0$: $M_i^X(E_0) = f_i^X(E_0, m_b, m_c, \mu_G^2, \mu_\pi^2, \rho_{LS}^3, \rho_D^3)\; (i = 1..4)$

  - cross-check lepton vs. hadron moments
  - compare $|V_{cb}|$ with $D^*\ell\nu$ result
  - compare non-perturbative parameters with other determinations

Combined Fit to E_l and M_x Moments

	$\lvert V_{cb}\rvert (10^{-3})$	m_b (GeV)	m_c (GeV)	μ_π^2 (GeV^2)	ρ_D^3 (GeV^3)	μ_G^2 (GeV^2)	ρ_{LS}^3 (GeV^3)	$\mathcal{B}_{c\ell\nu}$ (%)
Results	41.390	4.611	1.175	0.447	0.195	0.267	−0.085	10.611
δ_{exp}	0.437	0.052	0.072	0.035	0.023	0.055	0.038	0.163
δ_{HQE}	0.398	0.041	0.056	0.038	0.018	0.033	0.072	0.063
δ_{α_s}	0.150	0.015	0.015	0.010	0.004	0.018	0.010	0.000
δ_Γ	0.620							
δ_{tot}	0.870	0.068	0.092	0.053	0.029	0.067	0.082	0.175



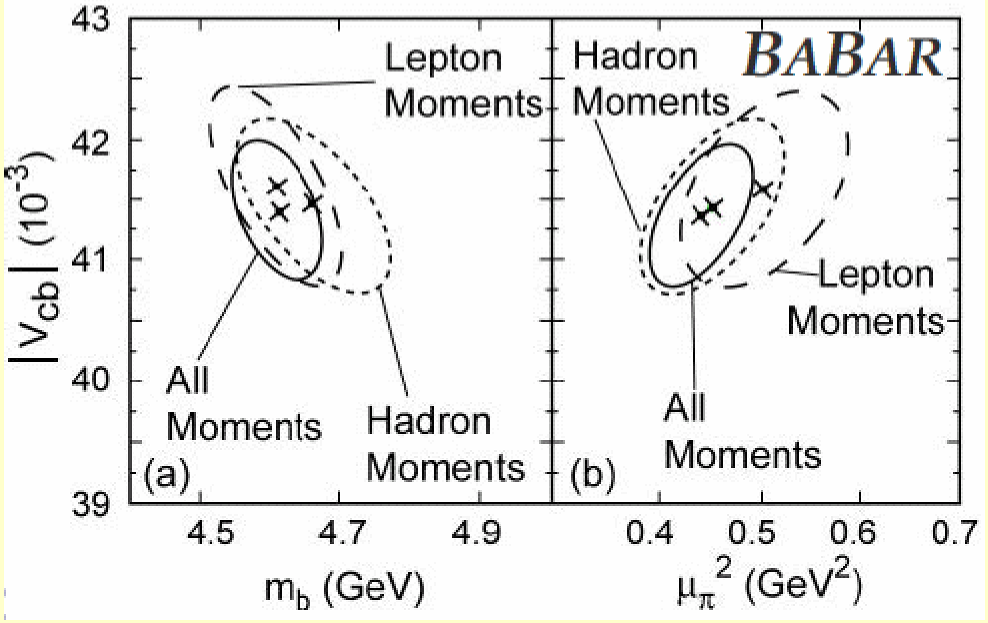
Calculations taken from Gambino and Uraltsev, hep/ph 0401063

high correlation between measurements :
⇒ this fit uses solid points only

$\chi^2 = 15.0$ (ndof = 20)

Cross-checks of fit results

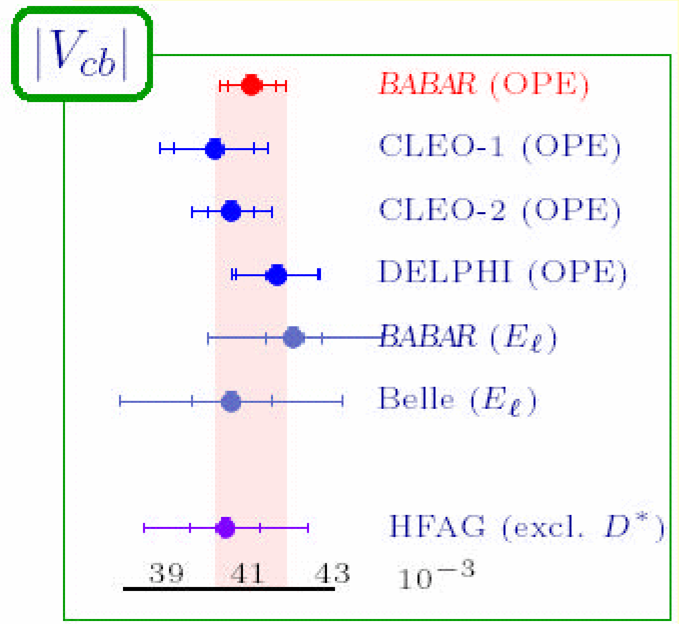
- E_e moments calculated up to $\alpha_s^2\beta_0$; M_X moments to α_s (higher orders small compared with exp error)
- Separate fits to E_e and M_x moments agree well



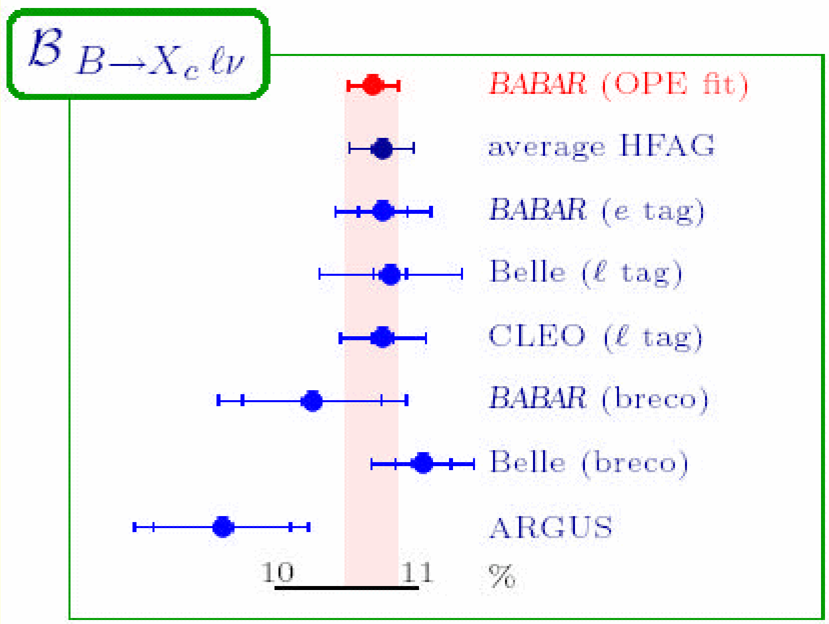
- Overall power of E_e and M_X moments is comparable
- Values for μ_G^2 and ρ_{LS}^3 are consistent with independent measurements based on m_{B*}-m_B and HQ sum rules.

OPE preliminary fit results

$$|V_{cb}| = (41.4 \pm 0.4_{\rm exp} \pm 0.4_{\rm HQE} \pm 0.6_{\rm th}) \times 10^{-3}$$
$$Br(B \to X_c e\nu) = (10.61 \pm 0.16_{\rm exp} \pm 0.06_{\rm HQE})\%$$
$$m_b(1\,GeV) = (4.61 \pm 0.05_{\rm exp} \pm 0.04_{\rm HQE} \pm 0.02_{\rm th})\,GeV$$
$$m_b(1\,GeV) - m_c(1\,GeV) = (3.44 \pm 0.03_{\rm exp} \pm 0.02_{\rm HQE} \pm 0.01_{\rm th})\,GeV$$
$$\mu_\pi^2 = (0.45 \pm 0.04_{\rm exp} \pm 0.04_{\rm HQE} \pm 0.01_{\rm th})\,GeV^2$$



- Different OPE schemes used -



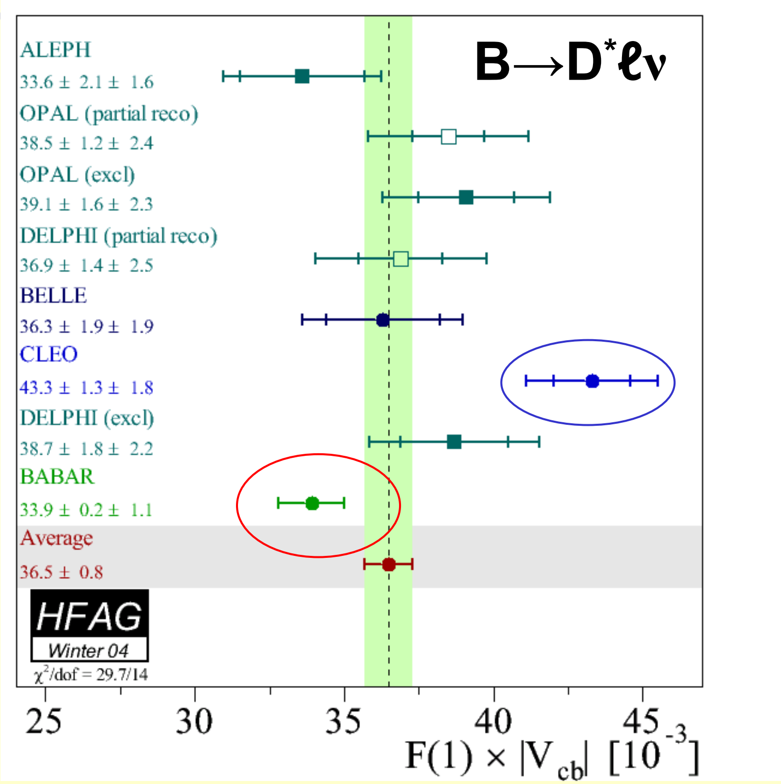
Comparison of inclusive and exclusive $|V_{cb}|$ determinations

- HFAG average from $D^*\ell\nu$

  $|V_{cb}| = (40.1 \pm 0.9_{exp} \pm 1.8_{theo})\times 10^{-3}$
- BaBar (preliminary) $D^*\ell\nu$

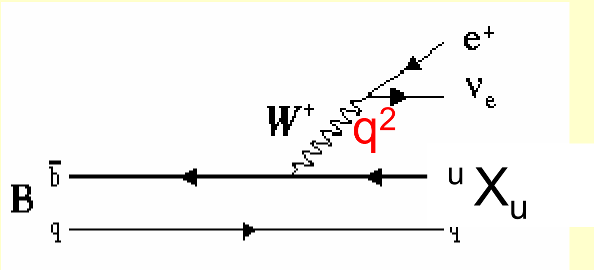
  $|V_{cb}| = (37.3 \pm 1.5_{exp} \pm 1.6_{theo})\times 10^{-3}$
- BaBar (preliminary) HQE fit to semileptonic moments

  $|V_{cb}| = (41.4 \pm 0.4_{exp} \pm 0.4_{HQE} \pm 0.6_{theo})\times 10^{-3}$



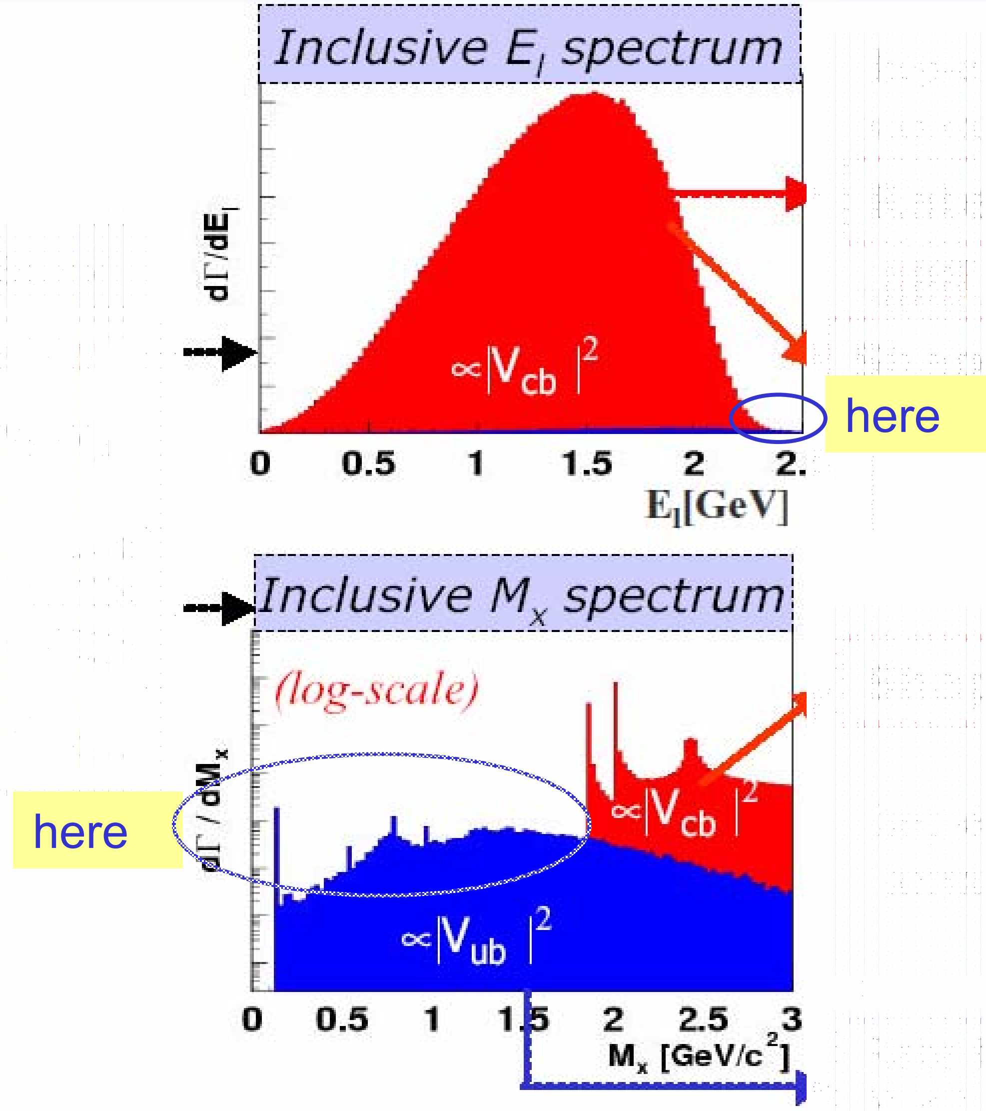
F(1)=0.92±0.03

$|V_{ub}|$ from inclusive decays

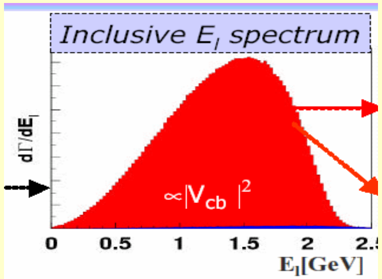


- OPE gives $|V_{ub}|$ from $\Gamma(B\rightarrow X_u \ell\nu)$ to <5%
- Challenges:
  - separate $b\rightarrow u$ from $b\rightarrow c$
  - calculate $|V_{ub}|$ from partial rate after $b\rightarrow c$ suppression cuts
- review of published results and methods
- new method
- outlook

Finding b→u decays

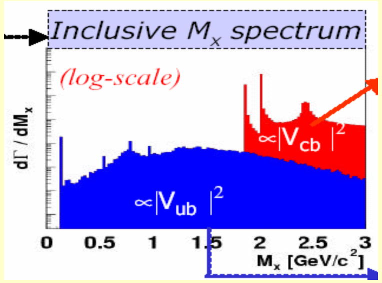


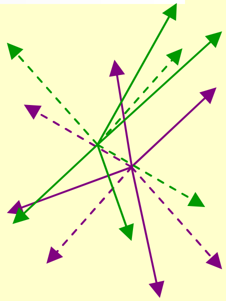
Lepton endpoint



- ☺ Experimentally clean for E_e > 2.3 GeV $\approx \frac{m_B^2 - m_D^2}{2m_B}$
- ☹ Can't go below E_e ~ 2.2 GeV due to $b \rightarrow c$ background
- ☠ OPE breaks down when restricted to endpoint region (need twist expansion in which power corrections are resummed into a light cone distribution function, or "shape function", which must be measured…)
- 😐 Determine shape function from $b \rightarrow s\gamma$ or perhaps from semileptonic decays
- Best measurements give $\sigma_{|V_{ub}|} / |V_{ub}| \sim 0.15$

Mass of recoiling hadrons



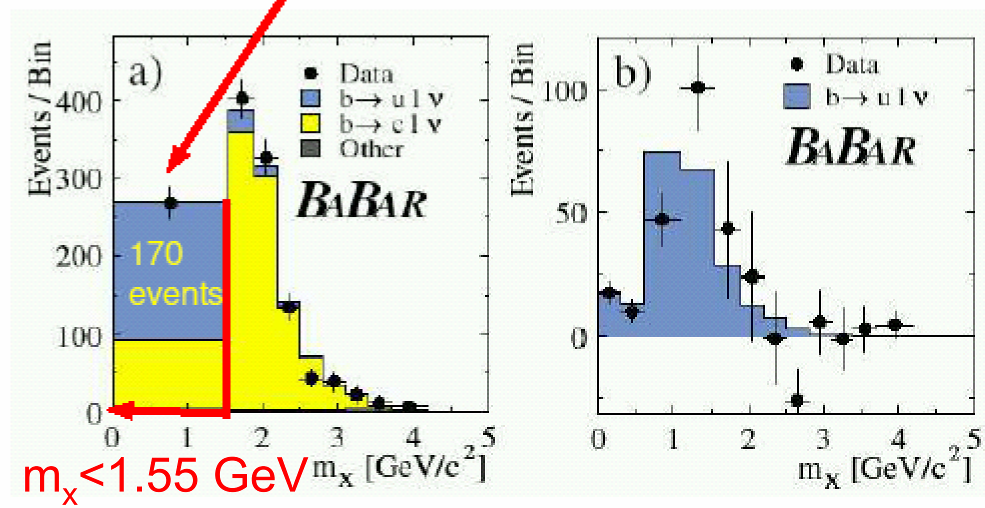


- Larger phase space (~70%) means smaller theoretical uncertainties (but not that simple…)
- Experimentally more challenging; need either B tagging (cleanest, very low efficiency) or "simulated annealing" (poor S/B, higher efficiency)
- Combine with q^2 (invariant mass of e-ν pair) to improve theory error?
- Early measurements show promise

BaBar $|V_{ub}|$ from tagged analysis

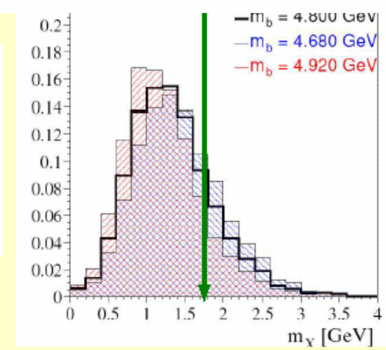
$$\frac{\mathcal{B}(B\to X_u\ell\nu)}{\mathcal{B}(B\to X\ell\nu)} = \frac{(N_{data}-N_{bg})/(\varepsilon^u_{sel} f_u)}{N_{sl}} \times \frac{\varepsilon_l^{sl}\varepsilon_t^{sl}}{\varepsilon_l^u\varepsilon_t^u}$$

- Reconstruct $B\to D^{(*)}n\pi$
- Select lepton $p_\ell>1$ GeV; good signal/background
- Perform kinfit to remaining particles to determine m_X
- Measure BF($B\to X_u\ell\nu$)



$$Br(B\to X_u l\nu) = (2.24\pm 0.27_{stat}\pm 0.26_{syst}\pm 0.39_{theo})\times 10^{-3}$$

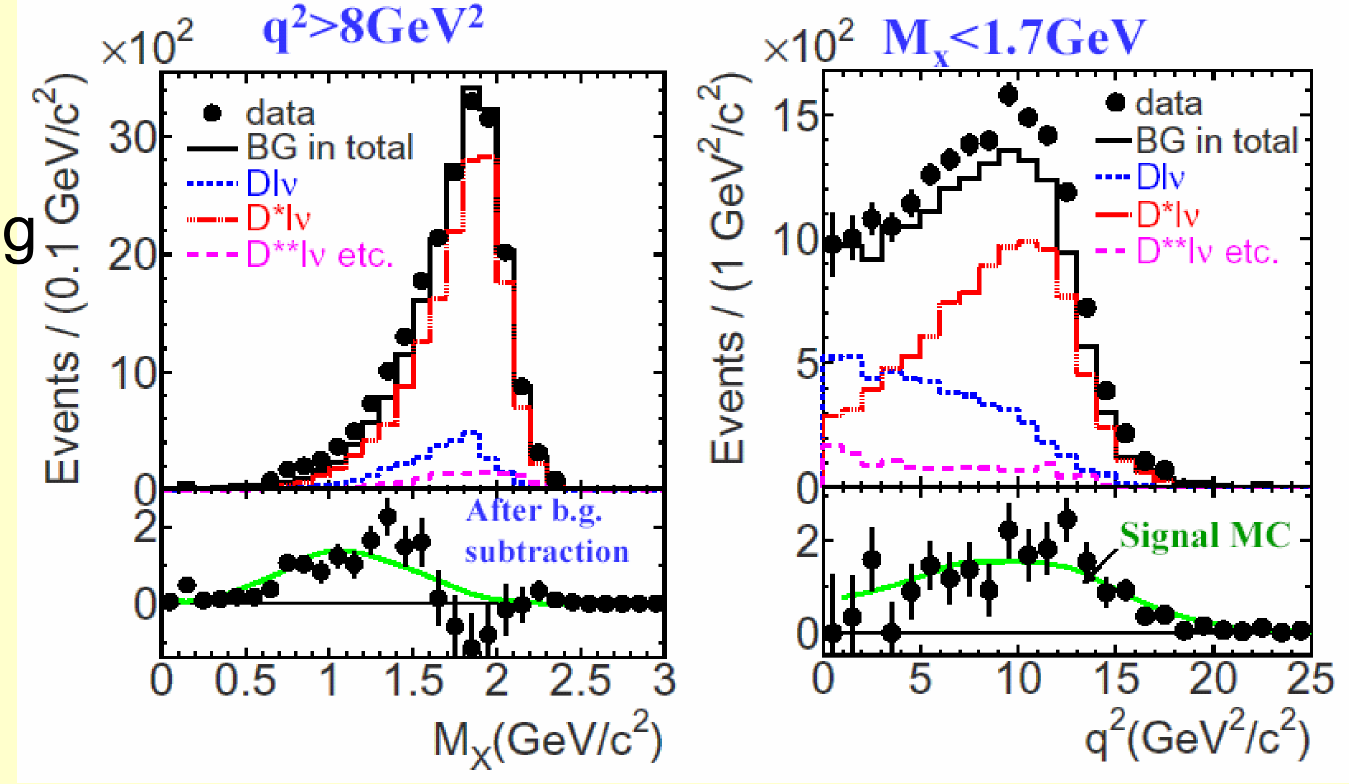
$$|V_{ub}| = (4.62\pm 0.28_{stat}\pm 0.27_{syst}\pm 0.40_{theo}\pm 0.26_{\Gamma})\times 10^{-3}$$



- In future consider q^2 to reduce theory error

Belle simulated annealing

- Try to assign particles to s.l. and other B using kinematics (m_B, E_B, m^2_{miss})
- Validate on $D^*\ell\nu$
- S/B poor

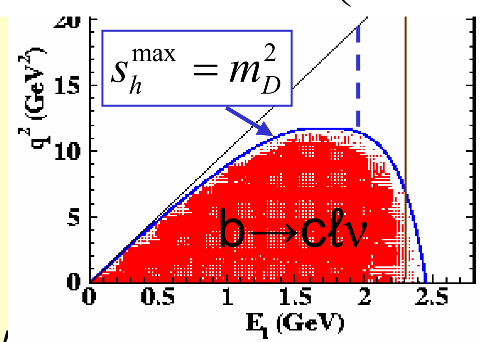


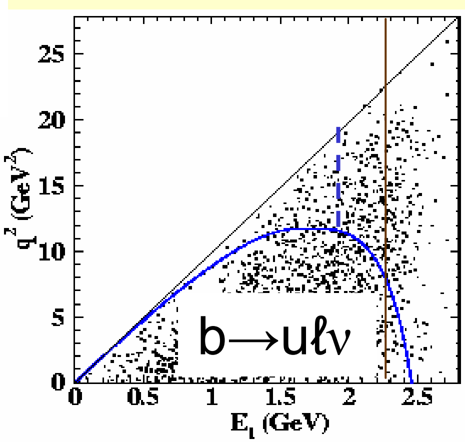
$$|V_{ub}| = (4.66 \pm 0.28(\mathrm{stat}) \pm 0.35(\mathrm{syst}) \pm 0.17(b \to c) \pm 0.08(b \to u) \pm 0.58(\mathrm{theo})) \times 10^{-3}$$
$$= (4.66 \pm 0.76) \times 10^{-3}$$

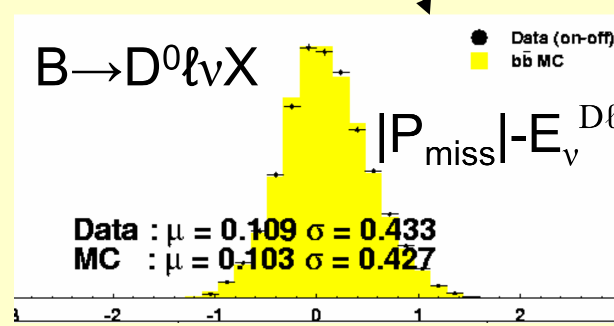
Lepton-pair invariant mass

- New method – combine E_e with q^2 to reduce E_e cut (and theory uncertainty); expect few ×10^3 events with S/B ~ 0.6.
- Estimate neutrino momentum based on “missing” momentum. Resolution is modest but usable
- Check / limit theory error by using $b\to u\ell\nu$ distributions (e.g. $\langle E_W+|P_W|\rangle \approx m_b$).

$$s_h^{max} = m_B^2 + q^2 - 2m_B\left(E_\ell + \frac{q^2}{4E_\ell}\right)$$







$|V_{ub}|$ from inclusive semileptonic decays - status and prospects

- Active area for theory and experiment
- New analyses with better acceptance and ability to measure decay distributions coming
- Expect significant progress if HQE parameters measured in $b \rightarrow c$ decays can be used in predictions for $d\Gamma(b \rightarrow u) / dy$
- My view – 10% measurements of $|V_{ub}|$ will appear in 2004/05.

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

- Extracting $|V_{ub}|$ from exclusive decays requires Form Factors (FF)
- $\pi \ell \nu$ is the best mode experimentally (low background) and theoretically:
  - Lattice QCD is making good progress on FF
  - measure $q^2 = m_W^2$ dependence to constrain theory
- status and prospects

Current status of $B \to \pi \ell \nu$

- CLEO
  - Based on neutrino reconstruction
  - PRD 68, 072003 (2003)

$$B\left(B^0 \to \pi^- \ell^+ \nu\right) = \left(1.33 \pm 0.18 \pm 0.11 \pm 0.01 \pm 0.07\right) \times 10^{-4}$$

$$\left|V_{ub}\right| = \left(3.24 \pm 0.22 \pm 0.13 \ {}^{+0.55}_{-0.39} \pm 0.09\right) \times 10^{-3}$$

- Belle… (2001 conference paper, never published)
- BaBar…

Tagged analyses

- Events where companion B is reconstructed are starting to be used:
  - Much better signal/background, kinematic acceptance
  - Much lower yield (10-100 times smaller than untagged)
  - Better for BF, but not yet for determining FF shapes
- Several tag methods:

Better for B^+ than for B^0:
- Fully reconstructed hadronic B decays
- "Fully" reconstructed semileptonic B decays to $D^{(*)}\ell\nu$

Only for B^0:
- Partially reconstructed semileptonic B decays (π_s-ℓ correlation)

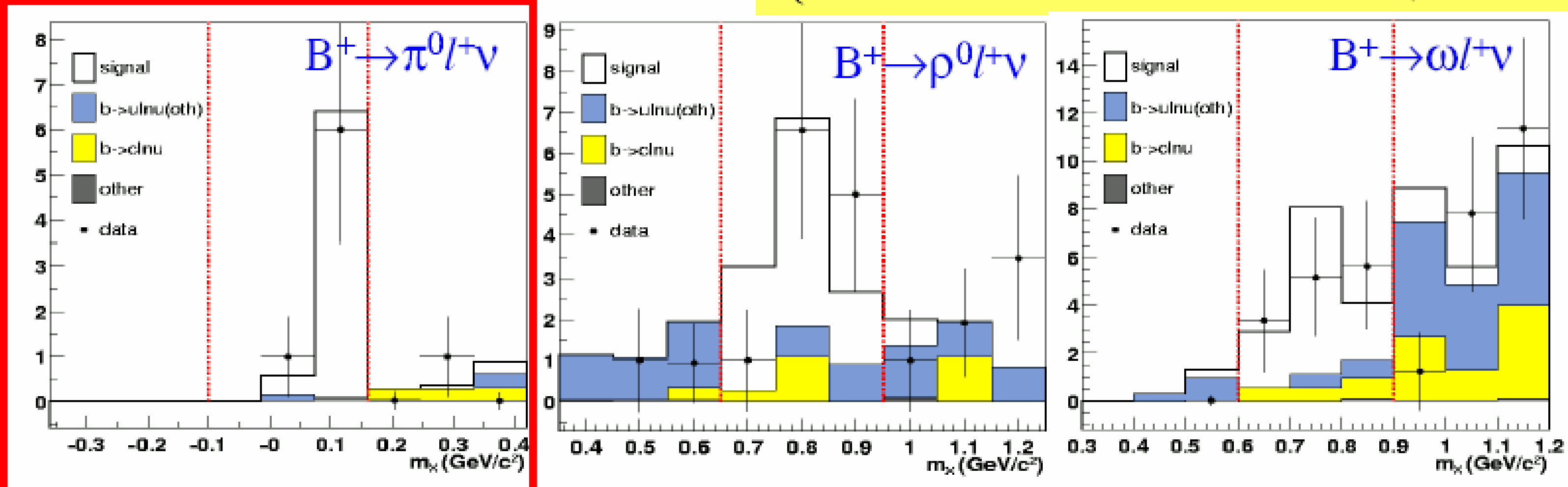
Exclusive $B^+ \to \pi^0, \rho^0, \omega\, l\, \nu$ decays

B recoil technique: as in inclusive V_{ub} analysis

- Small statistics
- Very high purity
- Loose cuts

  → small model dependence

$$\begin{cases} \mathcal{B}(B^+ \to \pi^0 l^+ \nu) = (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to "\rho^0" l^+ \nu) = (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to \omega l^+ \nu) = (2.20 \pm 0.92_{stat} \pm 0.57_{syst}) \cdot 10^{-4} \end{cases}$$



Lake Louise Winter Institute, 2004 Marcello Rotondo 14

Preliminary

$|V_{ub}|$ from exclusive semileptonic decays - status and prospects

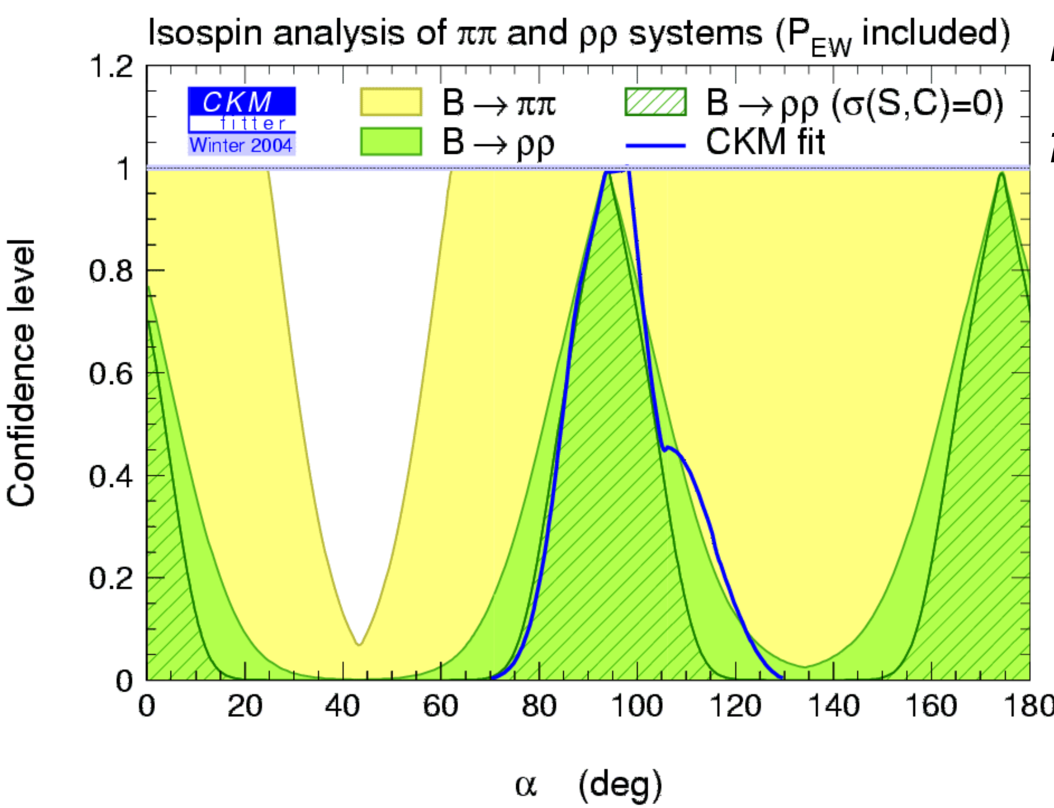
- Soon results on $B\to\pi\ell\nu$ - tagged and untagged analyses
  - Untagged analyses → form factor (q^2) shape
  - Tagged analyses → BF with small experimental systematics, convincing S/B
- Lattice calculations are becoming more believable
- Expect $\sigma(|V_{ub}|)$~10% in a year or two.

Summary

- Significant progress on $|V_{cb}|$ - accuracy 2% (inclusive), 5% (exclusive)
  - Clear progress due to HQE and precise measurements
- Anticipate improvements in $|V_{ub}|$ in near future
  - Cleaner and more comprehensive measurements
  - Improvements in theoretical methods
- B factories are systematically probing the weak and strong interactions of quarks

NEW

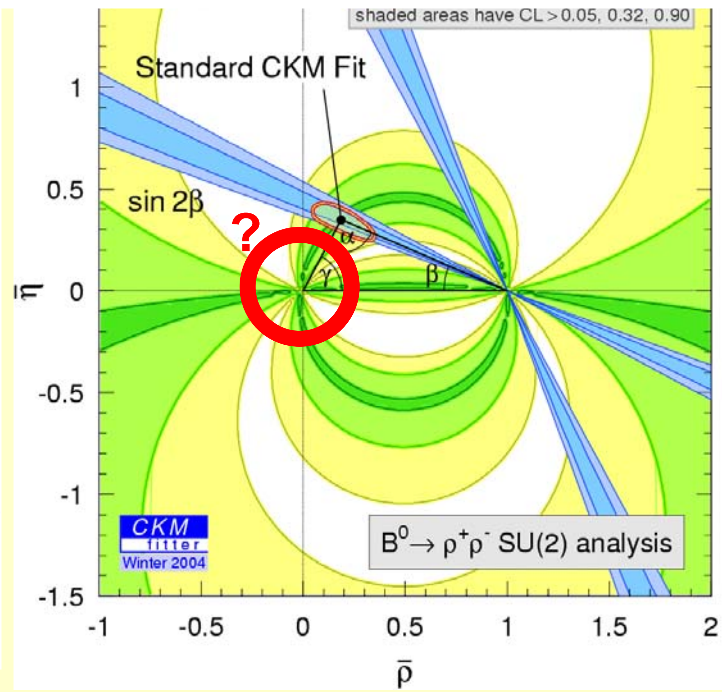
sin2α from B→ππ and B→ρρ decays



NEW

$$BR(\rho^+\rho^-) = (30 \pm 4_{stat} \pm 5_{syst})10^{-6}$$

$$f_{long} = 0.99 \pm 0.03(stat)^{+0.04}_{-0.03}(syst)$$



Other ingredients in ρρ isospin analysis:

$BR(\rho^+\rho^0) = (26.4 \pm 6.4)10^{-6}$ (*BABAR* & Belle), $BR(\rho^0\rho^0) = (0.62^{+0.72}_{-0.60} \pm 0.12)10^{-6}$

$f_{long}(\rho^+\rho^0) = 0.962^{+0.049}_{-0.065}$ (*BABAR* & Belle), $f_{long}(\rho^0\rho^0) = 1.0$

Plots from the CKMfitter group: http://ckmfitter.in2p3.fr