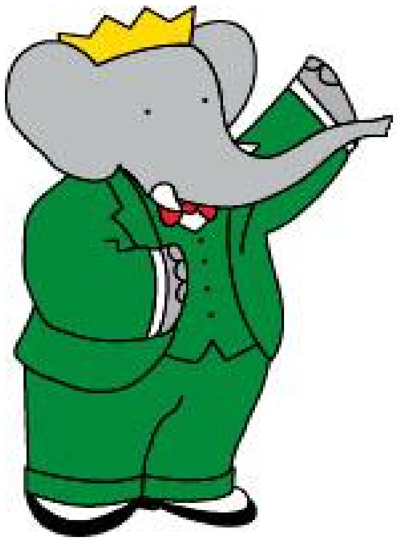
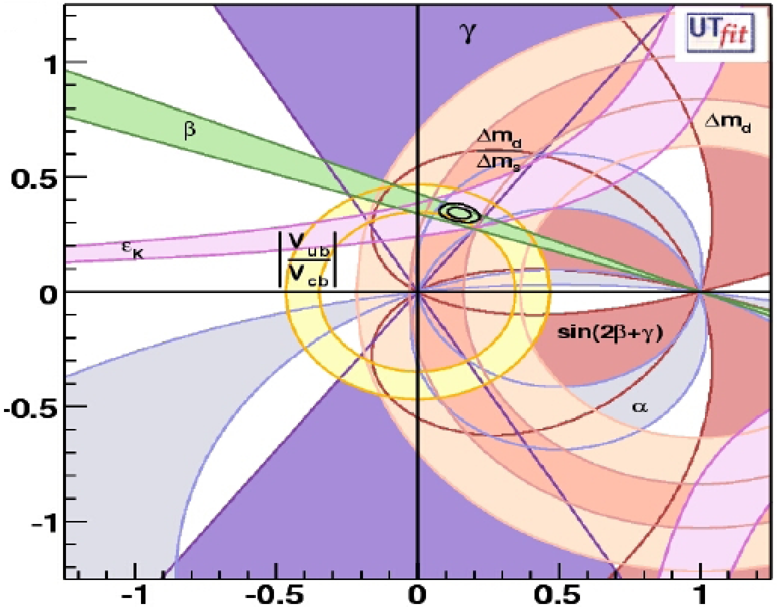
BEACH-2010, Perugia, June 22th 2010

Recent CKM Element results from BaBar and Belle





Nicola Gagliardi

On behalf of the BaBar Collaboration

Outline

- **Motivation:**
  - ✔ CKM matrix;
  - ✔ Plan of the talk: $|V_{ub}|$, $|V_{cb}|$, $|V_{td}/V_{ts}|$ and $|V_{us}|$;
- **$|V_{ub}|$ from B decays:**
  - ✔ Inclusive $B \to X_u l\nu$;
  - ✔ Exclusive $B \to \pi l\nu$;
- **$|V_{cb}|$ from B decays;**
  - ✔ Exclusive $B \to D l\nu$;
- **$|V_{td}/V_{ts}|$ from $b \to s\gamma$ $b \to d\gamma$ decays;**
- **$|V_{us}|$ from τ decays;**
- **Conclusions.**

Weak interaction and CKM Matrix

- In the Standard Model, the mass eigenstates and the weak eigenstates do not coincide and a unitary transformation connects the two sets using the **Cabibbo-Kobayashi-Maskawa matrix** (CKM);

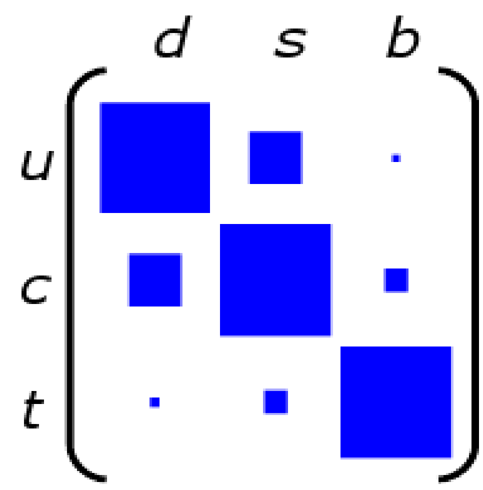
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \boldsymbol{V_{CKM}} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- V_{CKM} could be expressed in terms of three angles and one irremovable complex phase (source of *CP* violation).

$$\boldsymbol{V_{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\boldsymbol{V_{CKM}} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$A \sim 0.81, \lambda \sim 0.22, \rho \sim 0.2, \eta \sim 0.3$$



In this talk

Only a few of the most recent BaBar and Belle measurements will be presented:

$$\tau \to s \,,\ \frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)}$$

$$B \to \pi l \nu \,, B \to X_u l \nu$$

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$B \to X_d \gamma \,, B \to X_s \gamma$$

$$B \to D^{(*)} l \nu \,, B \to X_c l \nu$$

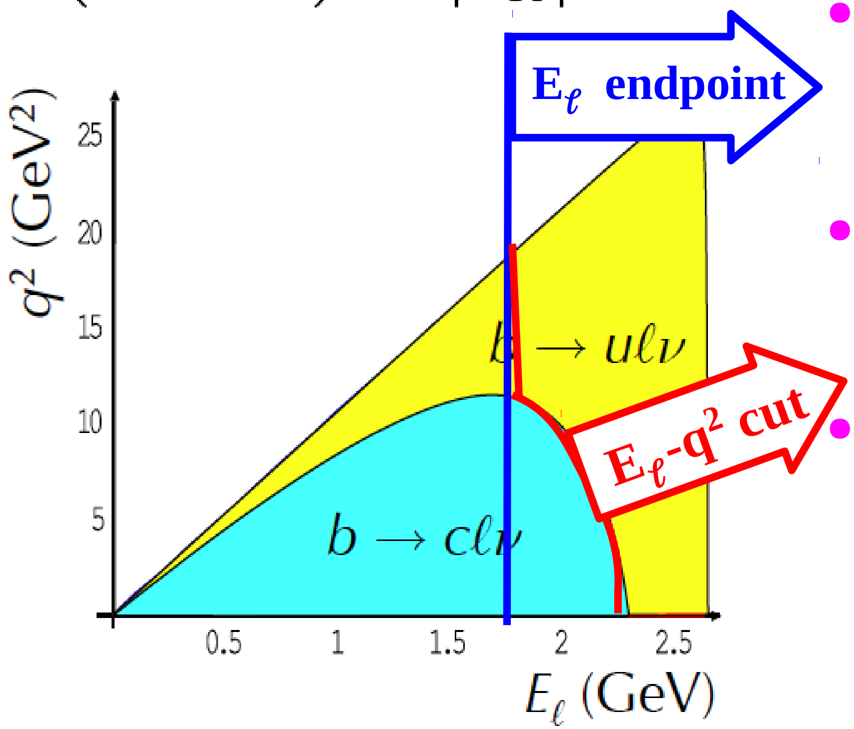
$|V_{ub}|$ from B decays

Inclusive $B \to X_u l\nu$

$$\Gamma(\bar{B} \to X_u \ell \bar{\nu}) = \underbrace{\frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}}_{\text{free quark decay}} \left[1 + \underbrace{\mathcal{O}(\alpha_s)}_{\text{perturbative correction}} + \underbrace{\mathcal{O}(1/m_b^2)}_{\text{non perturbative correction}} + H.C. \right]$$

OPE
~ 5% uncertaintly

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



- $m_u \ll m_c$ different kinematics
- measure $\Delta B(B \to X_u l\nu)$ in a region where the S/N is good and the $\Delta\Gamma_u$ is reliably calculable (exclude $b \to cl\nu$ decays)
- OPE convergence is compromised ($O(1/m_b)$)

$$\Delta B(B \to X_u \ell \nu) = \tau_B |V_{ub}|^2 \zeta_c$$

- theoretical acceptances are sensitive to b quark motion (Fermi motion) parametrized by **Shape Function.**

High theoretical error

Belle Multivariate analysis

The irreducible uncertainties in the measurements to date are related to limited phase space;

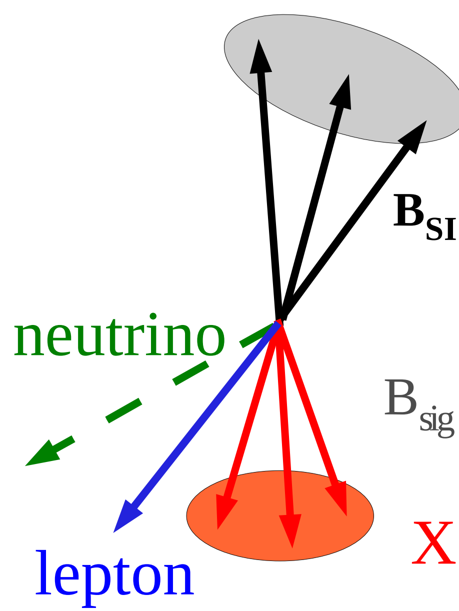
No need to place stringent, hard cuts that result in zero efficiency!

PRL 104:021801 (2010)

657M $B\bar{B}$

- Signal side: reconstruct high momentum lepton (p_{cms} > 1 GeV/c);
- **Boosted Decision Tree** cut with many input parameters (20 event parameters) : M^2_{miss} ,Q_{total} ,Q_{lepton} ,N_{lepton} ,Q(B),D^* partial reconstruction etc... ;
- 2D fit to $\mathbf{M_X, q^2}$ with background and signal floated to determine background yield;
- Measure absolute rate.

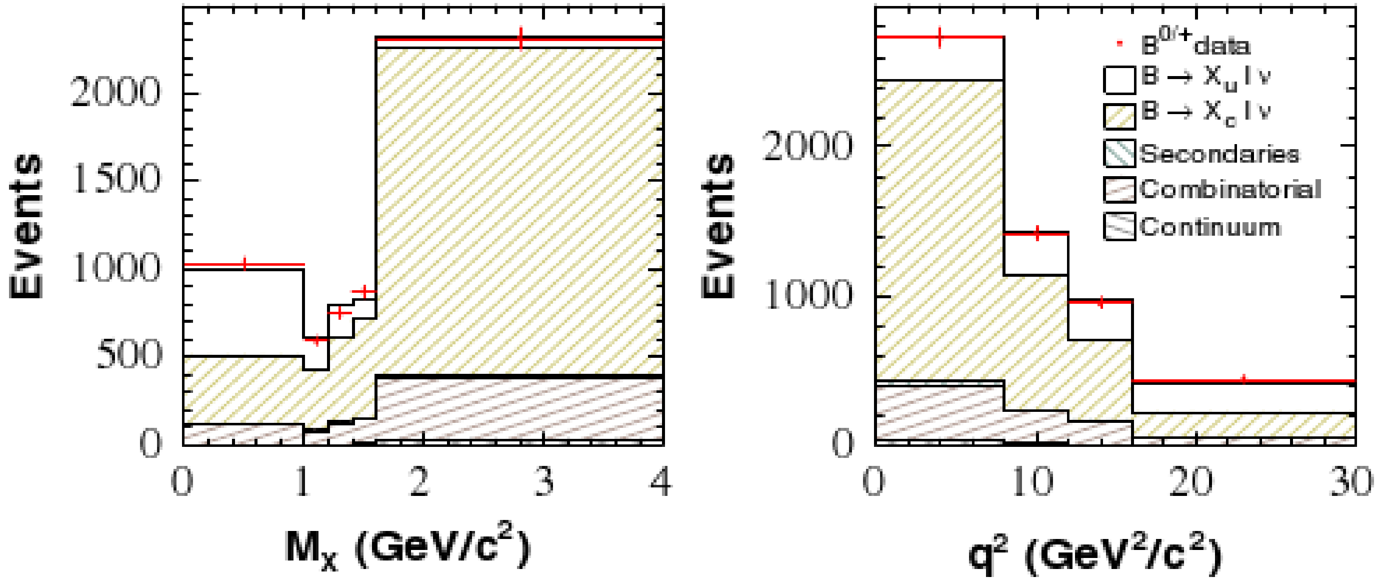
B_{TAG} : from hadronic decays



Belle Multivariate analysis: results

PRL 104:021801 (2010)

$\sim 1035\, B \rightarrow X_u l \nu$ *events*



657M $B\bar{B}$

$$\Delta B(B \rightarrow X_u l \nu;\, p_l > 1.0\, GeV) = 1.963 \times (1 \pm 0.088_{stat} \pm 0.081_{syst}) \times 10^{-3}$$

Theory	$\lvert V_{ub}\rvert 10^{3}$	Stat.%	Syst.%	Ther.%
BLNP	4.45	4.4	4.0	5.4
DGE	4.53	4.4	4.0	3.3
GGOU	4.47	4.4	4.0	3.0

$|V_{ub}|$ from exclusive $B \to \pi(\rho) l \nu$

- $|V_{ub}|$ can be extracted by studing $B^{0/+} \to \pi^{-/0}\ (\rho^{-/0})\, l^{+} \nu$ decays;
- Needed input from the theory in the calculation of the form factor:

$$\frac{d\Gamma(B^0 \to \pi^- l^+ \nu)}{dq^2\, d\cos\theta w_l} = |V_{ub}| \frac{G_F^2\, p_\pi^3}{32\pi^3} \sin^2\theta\, w_l \left| f_+(q^2) \right|^2$$

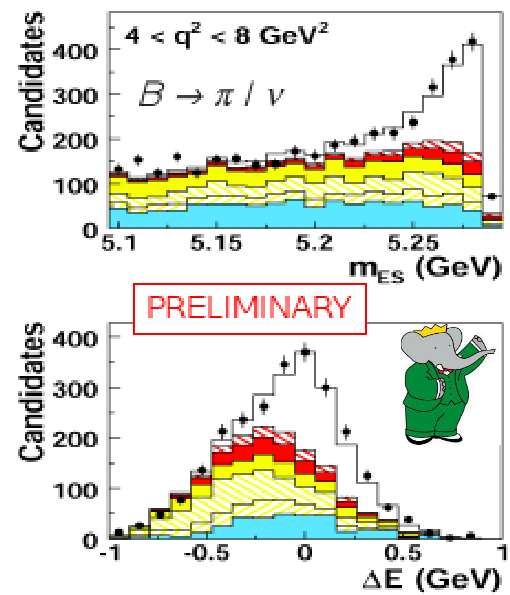
PRELIMINARY
Submitted to PRD
arXiv:1005.3288v1

$$m_{ES} = \sqrt{s/4 - p_B^2}$$

$$\Delta E = E_B - \sqrt{s}/2$$

$$377\text{M}\ B\bar{B}$$

- Neutrino 4-momentum inferred from the total energy and momentum in the event;
- Backgrounds (from $e^+e^- \to$ light quarks, charm and non-resonant $b \to u$) reduced by means of neural networks;
- Binned Maximum Likelihood fit to m_{ES} and ΔE in bins of q^2. Four channel $(\pi^-, \pi^0\, \rho^-, \rho^0)$ are fitted simultaneously imposing isospin.

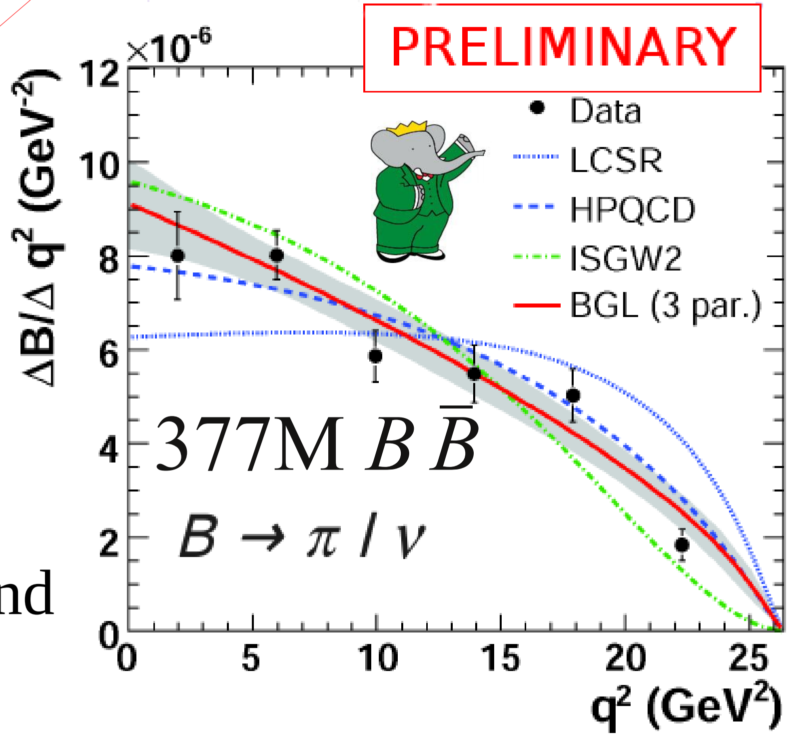


$|V_{ub}|$ from exclusive $B\to\pi(\rho)l\nu$

$$B(B^0\to\pi^- l^+\nu)=(1.41\pm0.05\pm0.07)\times10^{-4}$$
$$B(B^0\to\rho^- l^+\nu)=(1.75\pm0.15\pm0.27)\times10^{-4}$$

V_{ub} extracted integrating the FF's predictions

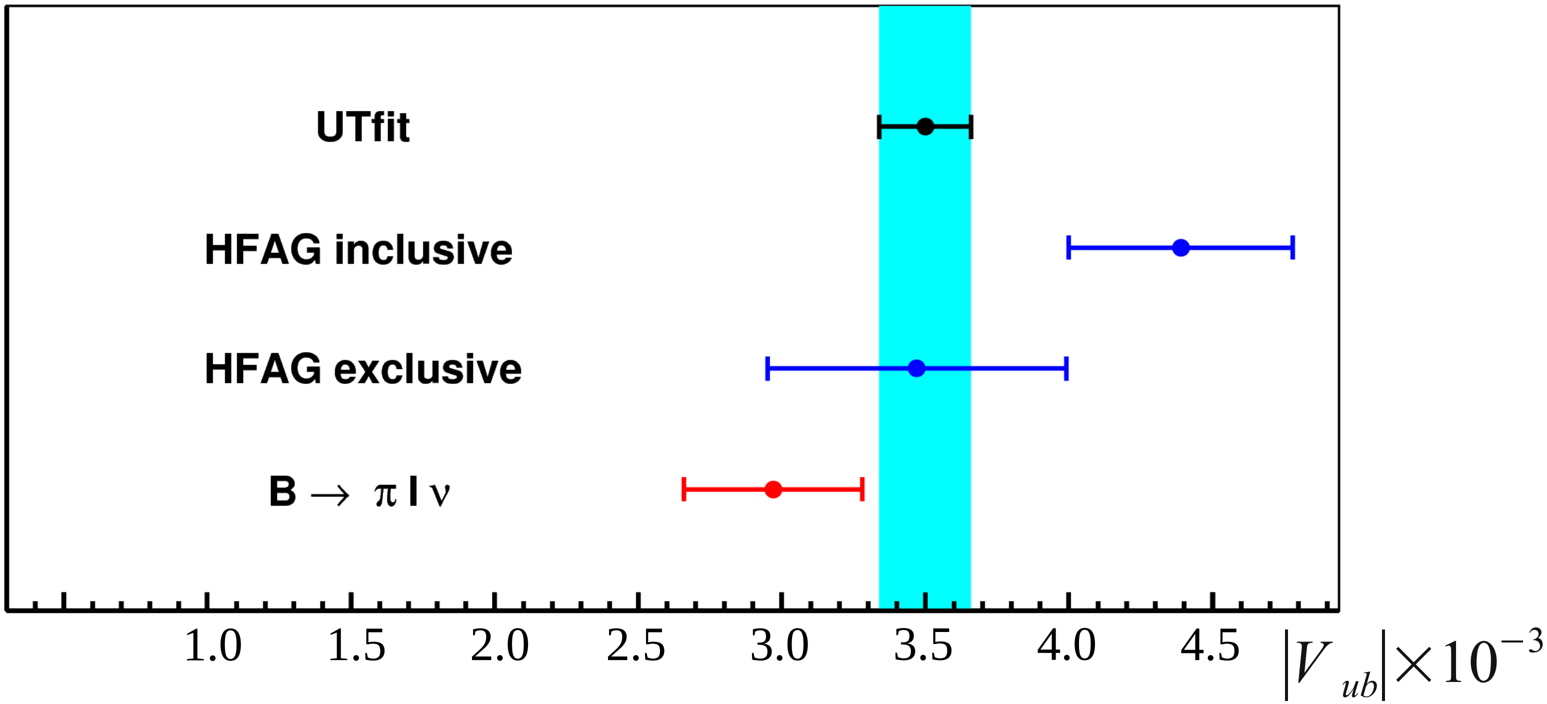
	q^2 Range (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
$B\to\pi\ell\nu$			
LCSR [15]	$0-16$	5.44 ± 1.43	$3.63\pm0.12^{+0.59}_{-0.40}$
HPQCD [22]	$16-26.4$	2.02 ± 0.55	$3.21\pm0.17^{+0.55}_{-0.36}$
LCSR [15]	$0-26.4$	7.72 ± 2.32	$3.46\pm0.10^{+0.68}_{-0.43}$
HPQCD [22]	$0-26.4$	9.35 ± 3.22	$3.14\pm0.09^{+0.68}_{-0.43}$
$B\to\rho\ell\nu$			
LCSR [16]	$0-16.0$	13.79	2.75 ± 0.24
LCSR [16]	$0-20.3$	17.15	2.58 ± 0.22
ISGW2 [14]	$0-20.3$	14.20	2.83 ± 0.24



..or we can simultaneously fit the data and theoretical predictions:

$$|V_{ub}|=(2.95\pm0.31)\times10^{-3}\ FNAL/MILC$$

$|V_{ub}|$ summary



Source	$\|V_{ub}\|$ (10^{-3})	Error (10^{-3})
$B \to \pi l \nu$	2.95	0.31
$B \to X_u l \nu$	4.37	0.39
UTFit	3.48	0.16

2.7 σ

$|V_{cb}|$ from B decays

$|V_{cb}|$ from exclusive $B \to D l \nu$

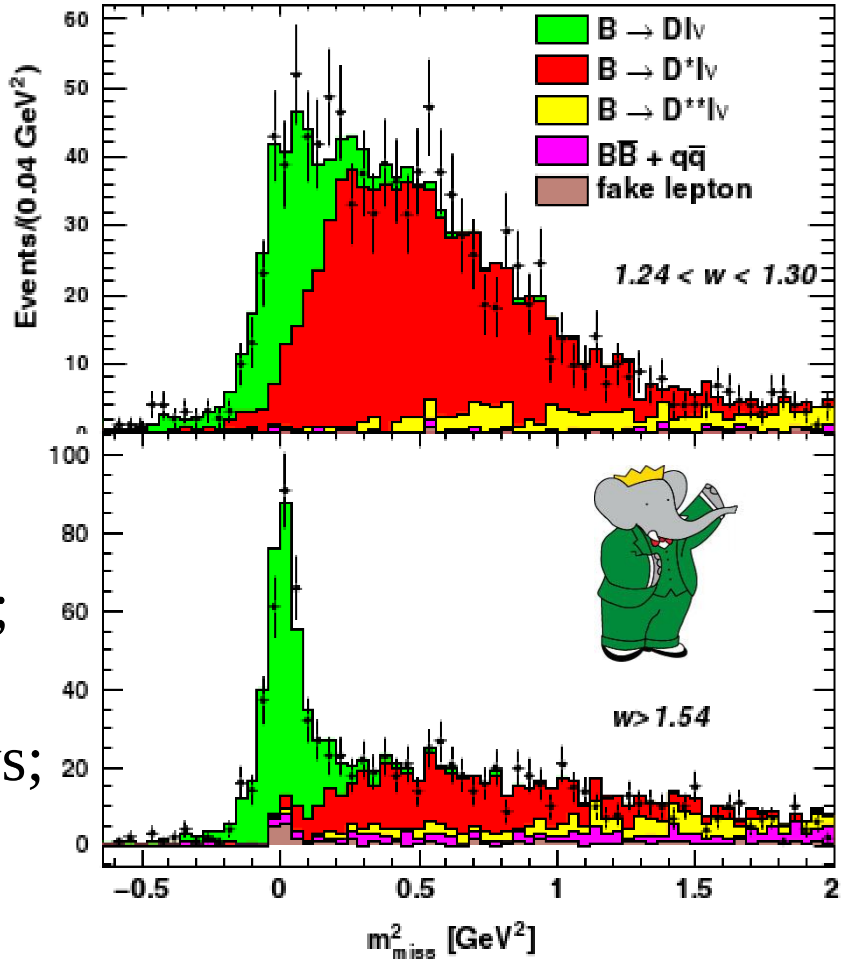
PRL 104, 011802(2010)

- Exclusive determination of $|V_{cb}|$ through:

$$\frac{d\Gamma(B\to D l \nu)}{d\omega} = \frac{G_F^2}{48\pi^3\hbar}(m_B+m_D)^2(\omega^2-1)^{\frac{3}{2}}|V_{cb}|^2 G(\omega)$$

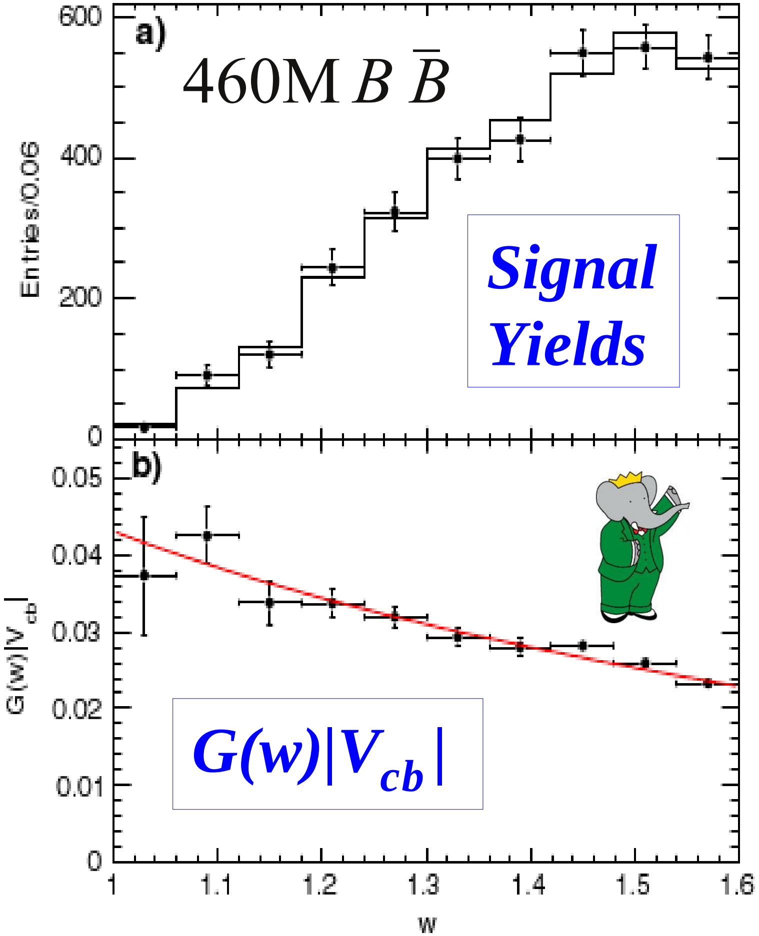
$$\omega = \frac{m_B^2+m_D^2-q^2}{2 m_B m_D} \qquad q^2 = (p_B - p_D)^2$$

- *G(w)* is a form factor, we use the Caprini et al parametrization;
- $|V_{cb}|$ is extracted extrapolating the differential decay at *w=1*, exploiting lattice QCD calculation;
- Data sample: 460 millions of *BB* pairs;
- $B \to D l \nu$ events searched for the recoil of fully reconstructed hadronic *B* decays;
- Discriminant variable: $m^2_{miss} = m^2_\nu$



$|V_{cb}|$ from exclusive $B \to D l \nu$

- χ^2 fit of $G(1)|V_{cb}|$ and ρ^2 in 10 bins of w (1 < w < 1.6);



PRL 104, 011802(2010)

- Results:

$$G(1)|V_{cb}| = (43.0 \pm 1.9 \pm 1.4) \times 10^{-3}$$
$$B(B^- \to D^0 l^- \nu) = (2.31 \pm 0.08 \pm 0.09)\%$$
$$B(B^0 \to D^+ l^- \nu) = (2.23 \pm 0.11 \pm 0.11)\%$$

- Extraction of $|V_{cb}|$:

Unquenched LQCD, Nucl.Phys 140,461

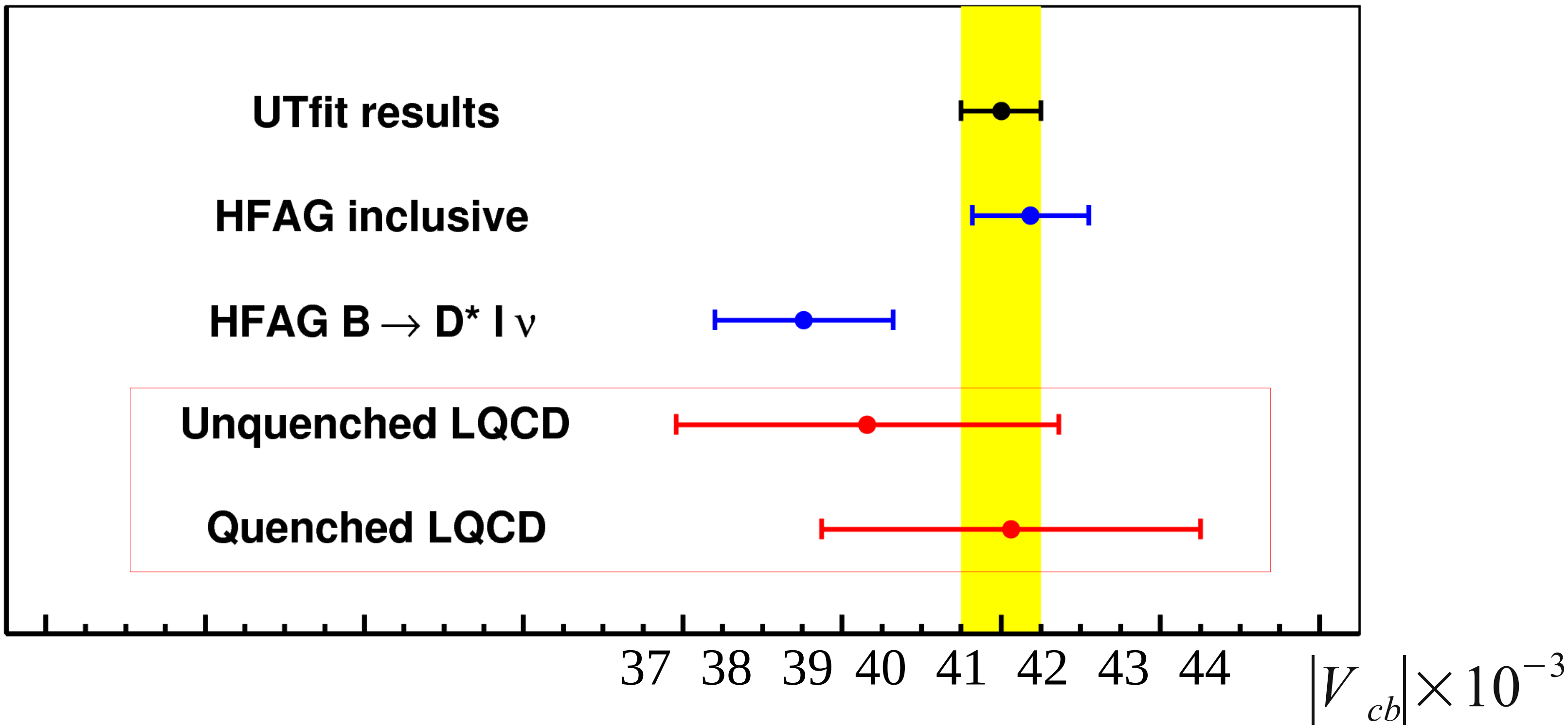
$$|V_{cb}| = (39.8 \pm 1.8 \pm 1.3 \pm 0.9) \times 10^{-3}$$

Quenched LQCD, Phys. Lett. B655, 45

Extrapolating at w=1 → $|V_{cb}| = (41.6 \pm 1.8 \pm 1.4 \pm 0.7) \times 10^{-3}$

Interpolating around w=1.2 → $|V_{cb}| = (41.4 \pm 1.3 \pm 1.4 \pm 1.0) \times 10^{-3}$

$|V_{cb}|$ summary



$$Exclusive\,|V_{cb}| \sim 2\,\sigma$$
$$lower\ than\ inclusive\,|V_{cb}|$$

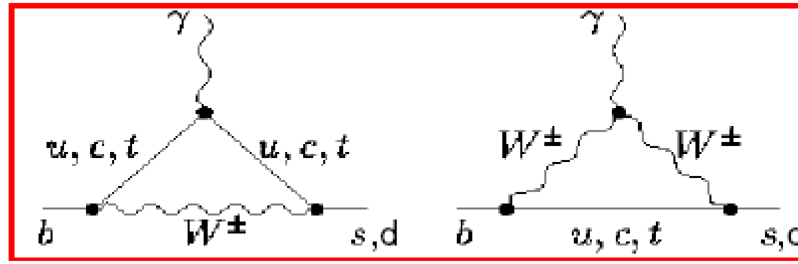
$|V_{td}/V_{ts}|$ from B decays

b→dγ and b→sγ decays and $|V_{td}/V_{ts}|$

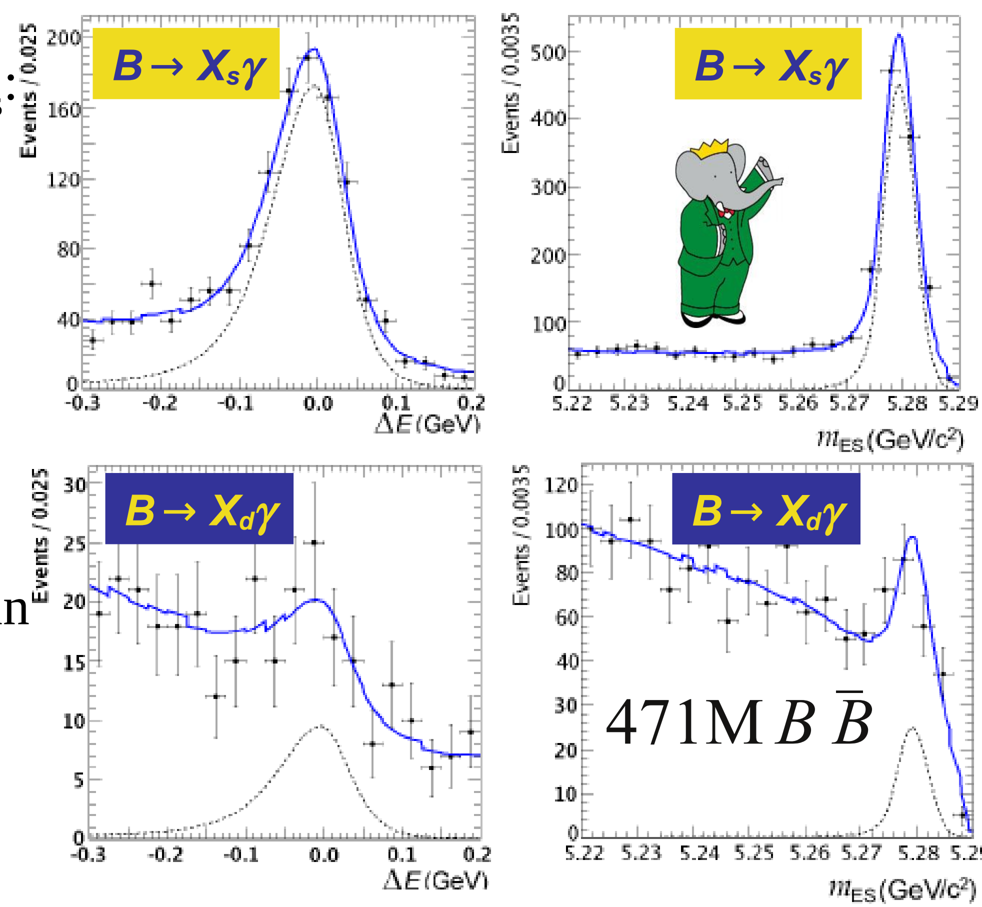
- The decays b→dγ and b→sγ are one loop electroweak penguin diagrams
- In the SM the rate b→dγ is suppressed relative to b→sγ by a factor $|V_{td}/V_{ts}|^2$
- In theories beyond the SM, new particles may appear in the loop (probe for NP)
- Reconstructed 7 decay modes for X_d,X_s:

$B \to X_d\gamma$	$B \to X_s\gamma$
$B^0 \to \pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\gamma$
$B^+ \to \pi^+\pi^0\gamma$	$B^+ \to K^+\pi^0\gamma$
$B^+ \to \pi^+\pi^-\pi^+\gamma$	$B^+ \to K^+\pi^+\pi^-\gamma$
$B^0 \to \pi^+\pi^-\pi^0\gamma$	$B^0 \to K^+\pi^-\pi^0\gamma$
$B^0 \to \pi^+\pi^-\pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\pi^+\pi^-\gamma$
$B^+ \to \pi^+\pi^-\pi^+\pi^0\gamma$	$B^+ \to K^+\pi^-\pi^+\pi^0\gamma$
$B^+ \to \pi^+\eta\gamma$	$B^+ \to K^+\eta\gamma$

- Signal yields extracted with a 2D maximum likelihhod to the ΔE and m_{ES} in two hadronic mass bins:
  - 0.5-1.0 GeV (dominated by B→(ρ,ω)γ and B→K*γ resonances
  - 1.0-2.0 GeV (non-resonant region)



(arXiv:1005.4087v1 submitted to PRL)



$|V_{td}/V_{ts}|$

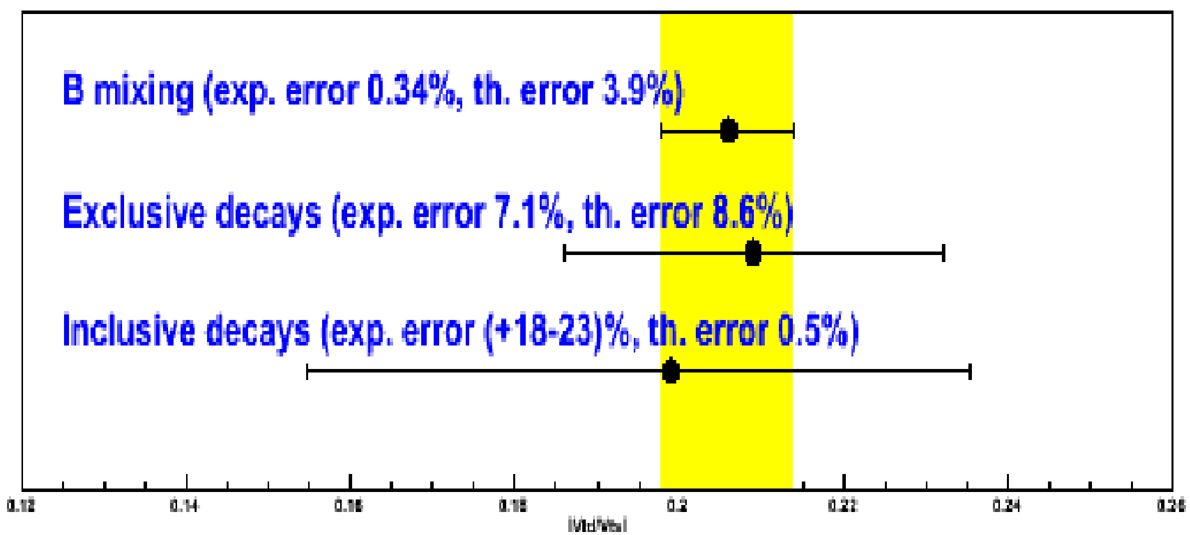
$$\frac{B(b\rightarrow d\gamma)}{B(b\rightarrow s\gamma)}=0.040\pm0.009_{stat}\pm0.010_{syst}$$

Measurements of $B\rightarrow K^*\gamma$, $b\rightarrow s\gamma$ and $B\rightarrow(\rho,\omega)\gamma$ all compatible with previous results.

$$\left|\frac{V_{td}}{V_{ts}}\right|=0.199\pm0.022_{stat.}\pm0.024_{syst.}\pm0.002_{th.}$$

Ali,Asatrian,Greub, Phys. Lett. B 429, 87 (1998)

Measurements of $|V_{td}/V_{ts}|$ compatible with previous result



$|V_{us}|$ from τ decays

B factories as τ factories

- B factories are also τ factories:

$$\sigma_{\tau\tau} = 0.9\, nb, \sigma_{BB} = 1.1\, nb$$

- Area of physics with recent results:
  - Precise τ branching fractions;
  - τ mass;
  - Constraint on Lepton Flavor Violation;
  - $|V_{us}|$ from τ decays
    - Inclusive $\tau \to s$ decays;
    - Ratio of BR

$|V_{us}|$ from inclusive $\tau \to s$ decays

τ decay rate into hadrons:

$$R_\tau = \frac{\Gamma(\tau \to hadrons\ \nu_\tau)}{\Gamma(\tau \to e\,\bar{\nu}_e \nu_\tau)} = R_{\tau,\,strange} + R_{\tau,\,non-strange}$$

Branching fractions are experimental inputs for $|V_{us}|$ determinations:

$$|V_{us}|^2 = \frac{R_{\tau,\,strange}}{R_{\tau,\,non-strange}/|V_{ud}|^2 + \delta R_{\tau,\,theory}}$$

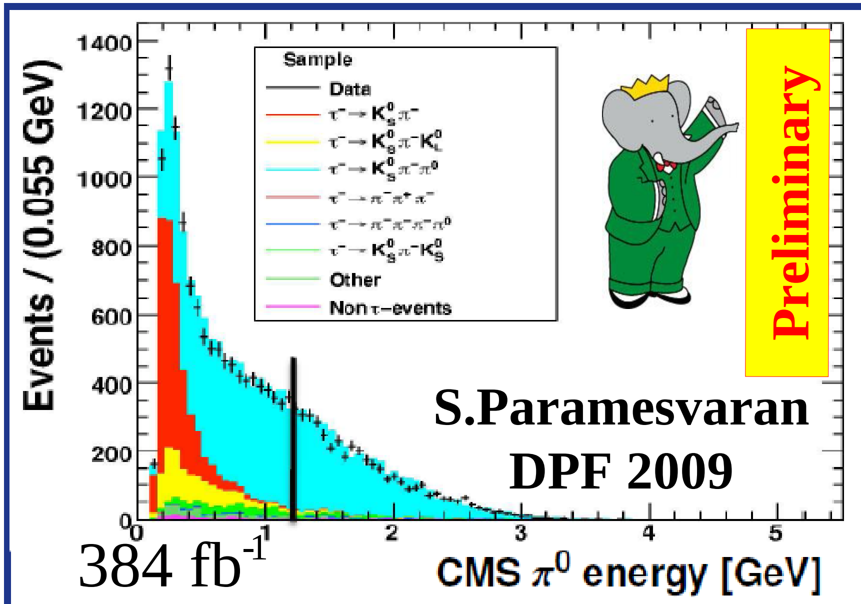
SU(3) symmetry breaking term correction obtained from OPE,FESR

hadronic system in $\tau \to X_s \nu$	ICHEP08 averages (%)	References
K^- [from τ decay]	0.690 ± 0.010	PDG 2006 + BaBar 2008 prelim.
[indirect, from $K_{\mu 2}$]	(0.715 ± 0.004)	Gamiz *et al.*, PoSKAON:008,2008
$K^-\pi^0$	0.426 ± 0.016	BaBar 2007
$\overline{K}^0\pi^-$	0.835 ± 0.022 ($S = 1.4$)	Belle 2008, BaBar 2008
$K^-\pi^0\pi^0$	0.058 ± 0.024	PDG 2006
$\overline{K}^0\pi^0\pi^-$	0.360 ± 0.040	PDG 2006
$K^-\pi^-\pi^+$	$0.273 \pm 0.002 \pm 0.009$	Phys. Rev. Lett. 100:011801,2008
$(\overline{K}3\pi)^-$ (est'd)	0.074 ± 0.030	ALEPH 2005
$K_1(1270) \to K^-\omega$	0.067 ± 0.021	ALEPH 2005
$(\overline{K}4\pi)^-$ (est'd)	0.011 ± 0.007	ALEPH 2005
$K^-\eta$	$0.016 \pm 0.05 \pm 0.09$	Phys. Lett. B672:209-218,2009
$K^{*-}\eta$	$0.013 \pm 0.12 \pm 0.09$	
$K^-\phi$	0.0037 ± 0.0003 ($S = 1.3$)	Belle 2006, BaBar 2007
TOTAL	2.8447 ± 0.0688 (2.8697 ± 0.0680)	

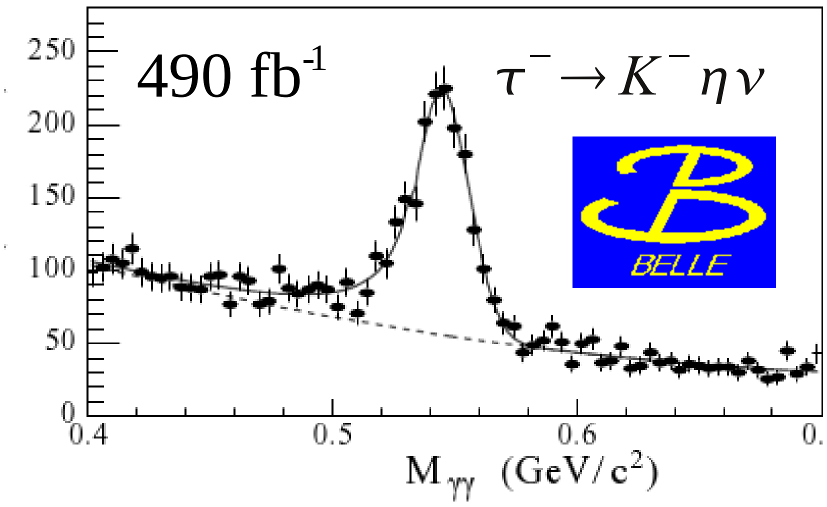
Strange τ decays

- Lepton tag used to identify one hemisphere-other hemisphere contains signal particle
- High π^0 energy required in CMS $\rightarrow$high purity (93%)
- π^0 trajectory within 90° of $K_s\pi^0$ momentum

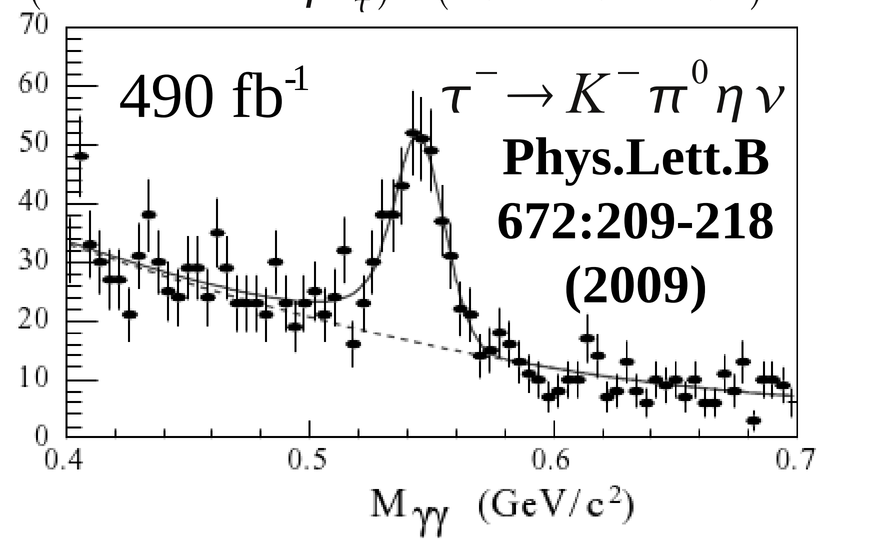
$$B(\tau^- \rightarrow \bar{K}^0 \pi^- \pi^0 \nu_\tau) = 0.342 \pm 0.006 \pm 0.015$$



$$B(\tau^- \rightarrow K^- \eta \nu_\tau) = (1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$$



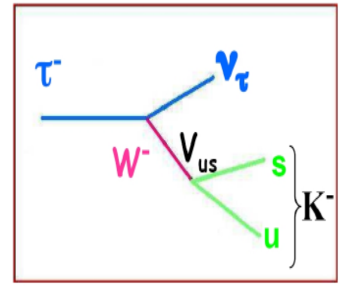
$$B(\tau^- \rightarrow K^- \pi^0 \eta \nu_\tau) = (4.6 \pm 1.1 \pm 0.4) \times 10^{-5}$$

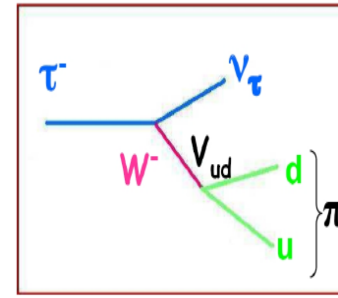


Alternative $|V_{us}|$ determination

- Can obtain $|V_{us}|$ through the BF ratio:

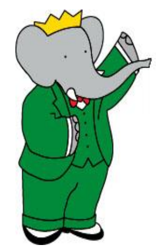
$$\frac{B(\tau \to K \nu_\tau)}{B(\tau \to \pi \nu_\tau)} = \frac{f_k^2 |Vus|^2 (1 - m_k^2/m_\tau^2)^2}{f_\pi^2 |Vud|^2 (1 - m_\pi^2/m_\tau^2)^2} (1 + \delta_{LD})$$





(M.Roney CIPANP 2009)

- δ_{LD} long distance EW correction
- $|V_{us}|$ from allowed beta decays
- Ratio f^2_K/f^2_π from lattice QCD
- Select ττ events with:
  - One τ decaying into 3 pions
  - The other into the signal decay



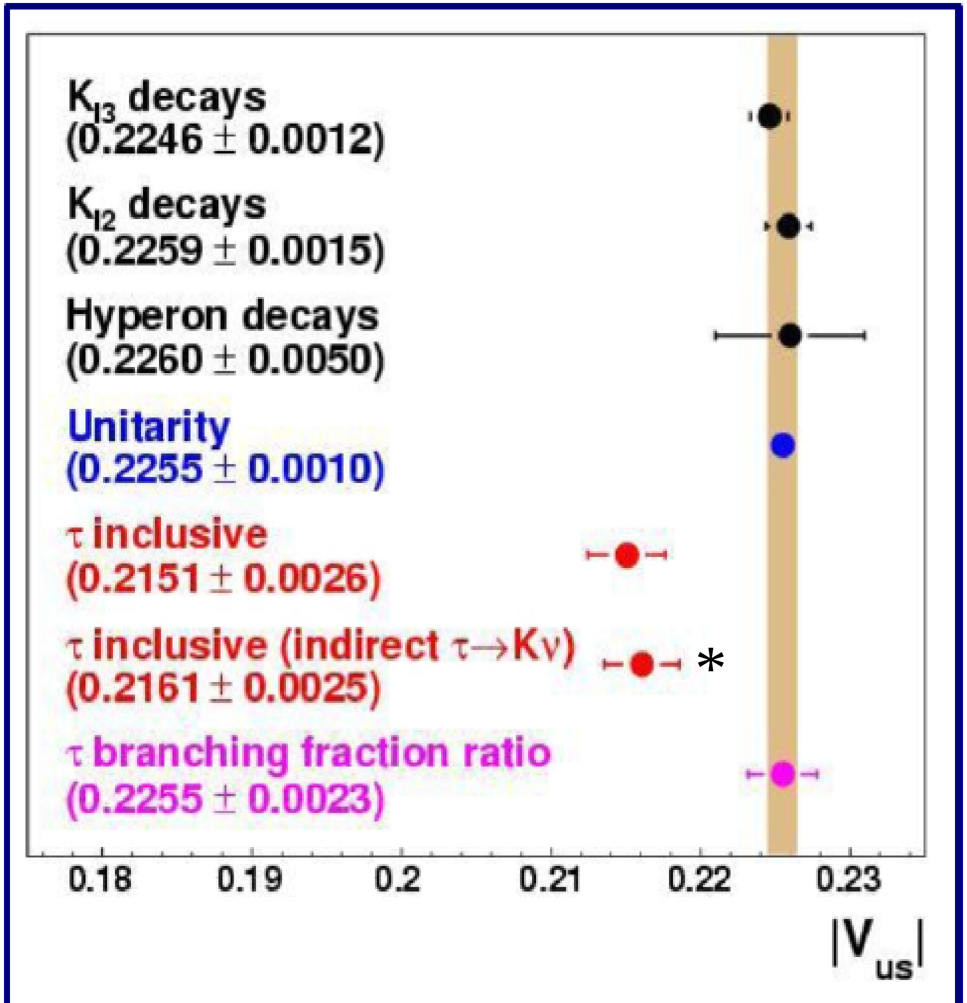
$467\ fb^{-1}$

Branching Ratios (Preliminary)
$B(\tau^- \to \pi^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
$(5.945 \pm 0.014 \pm 0.061) \times 10^{-1}$
$B(\tau^- \to K^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
$(3.882 \pm 0.032 \pm 0.056) \times 10^{-2}$
$B(\tau^- \to K^- \nu_\tau)/B(\tau^- \to \pi^- \nu_\tau)$
$(6.531 \pm 0.056 \pm 0.093) \times 10^{-2}$

By measuring ratios, benefit from systematic uncertainty cancellation

Measure: $\frac{BF(\tau^- \to \pi^- \nu_\tau)}{BF(\tau^- \to e^- \nu_\tau \bar{\nu}_e)}$ $\frac{BF(\tau^- \to K^- \nu_\tau)}{BF(\tau^- \to e^- \nu_\tau \bar{\nu}_e)}$ $\frac{BF(\tau^- \to K^- \nu_\tau)}{BF(\tau^- \to \pi^- \nu_\tau)}$

$|V_{us}|$ status



(*) indirect τ→Kν

Use precise measurement of B[K→μν(γ)] to get indirect measurements of B[τ→Kν(γ)]

Rev.Mod.Phys 78 1043(2006)

Unitarity	0.2255 ± 0.0010
inclusive τ → s	0.2151 ± 0.0026
$\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$	0.2255 ± 0.0023

- $|V_{us}|$ from inclusive τ→s decays results in 3σ discrepancy from unitarity;
- However, still need to complete the program of τ→s measurements
  - ➔Next: $(K3\pi)^-, K3\pi^0, K4\pi^0$;
- $|V_{us}|$ from branching fraction ratio compatible consistent with unitarity.

Conclusions

- $|V_{ub}|$ determinations (incl/excl) differ by 2.7σ; latest updates have increased this discrepancy
  - $|V_{ub}|$ exclusive: 2.95 ± 0.31;
  - $|V_{ub}|$ inclusive: 4.37 ± 0.39;

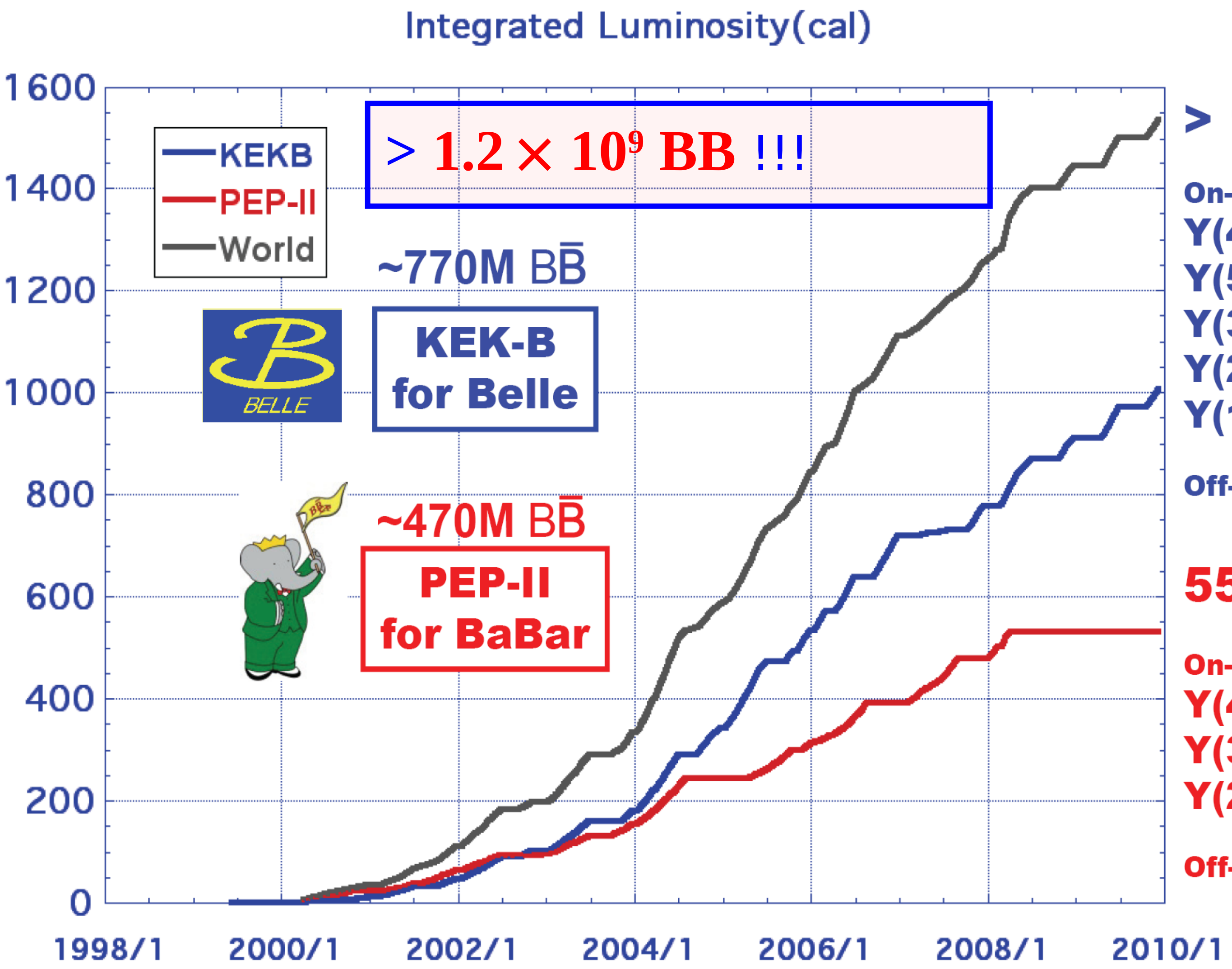
- $|V_{cb}|$ determinations (incl/excl) differ by ~2.3σ; their average is $(40.9 \pm 1.0)\times 10^{-3}$;

- $|V_{td}/V_{ts}|$ compatible with previous measurements

- $|V_{us}|$:
  - inclusive $\tau \to s$ decays results in 3σ discrepancy from unitarity; however, still need to complete $\tau \to s$ measurements
  - BF ratio compatible consistent with unitarity.

Backup slides

The B factories



> 1000 fb^{-1}

On-resonance samples:
Y(4S):711 fb^{-1}
Y(5S):121 fb^{-1}
Y(3S): 3.0 fb^{-1}
Y(2S): 24 fb^{-1}
Y(1S): 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

553.5 fb^{-1}

On-resonance samples:
Y(4S): 433 fb^{-1}
Y(3S): 30.2 fb^{-1}
Y(2S): 14.5 fb^{-1}

Off-resonance: 54 fb^{-1}