Inclusive semileptonic B decays: experimental

Elisabetta Barberio
University of Melbourne

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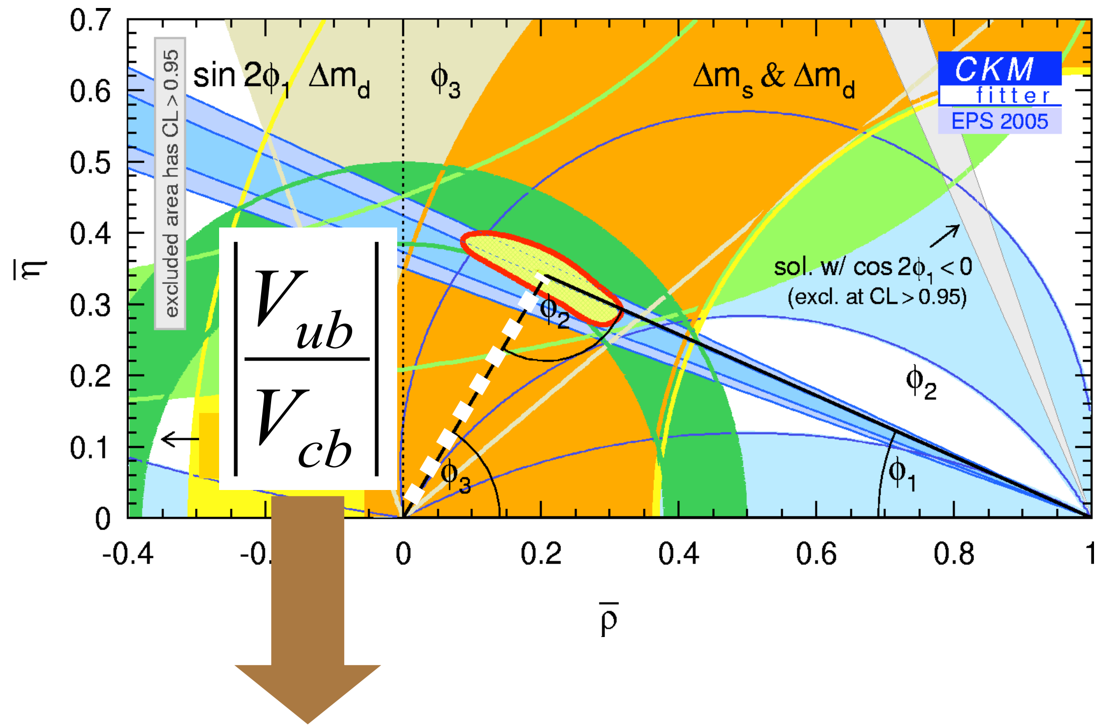
Standard Model Consistency Tests

V_{ub} and V_{cb} provide a test of CP violation in the Standard Model comparing the measurements on the $(\rho,\ \eta)$ plane

The width of the green ring need to be reduced to match $\sin 2\beta$ and other measurements

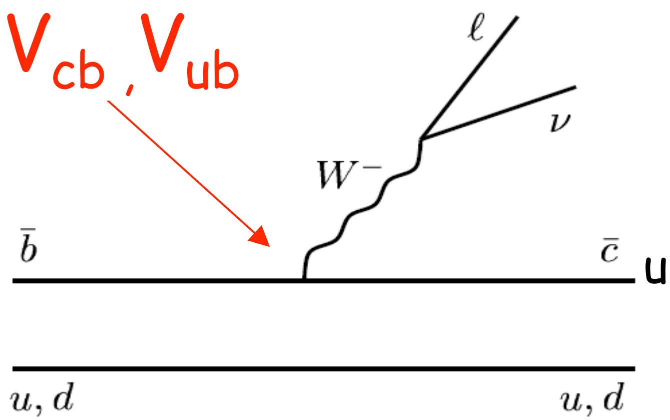


The error on the ring width is dominated by V_{ub}

Goal: Accurate determination of $|V_{ub}|$

Semileptonic B decays

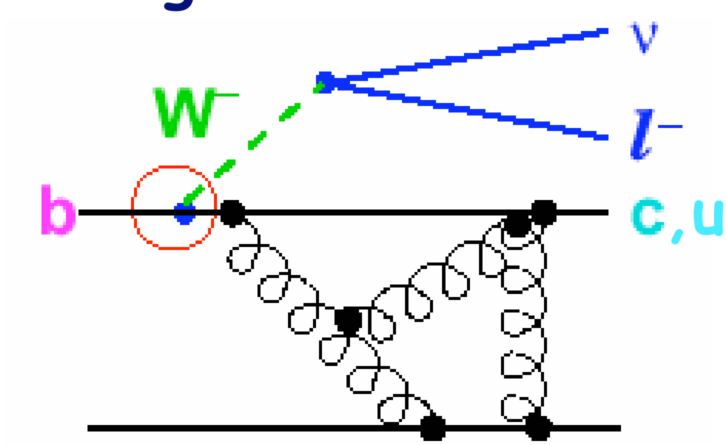
tree level, short distance:



decay properties depend directly on $|V_{cb}|$, $|V_{ub}|$, m_b

perturbative regime (α_s^n)

+ long distance:



But quarks are bound by soft gluons: non-perturbative (Λ_{QCD}) long distance interactions of b quark with light quark

Inclusive semileptonic decays

Many theorists love inclusive semileptonic decays

Short distance is calculable

Long distance leading order and short distance contribution are cleanly separated and probability to hadronnize is 1

To compare Operator Product Expansion predictions with experiments:

integration over neutrino and lepton phase space provides smearing over the invariant hadronic mass of the final state

Inclusive semileptonic decays

V_{cb} vs V_{ub}

V_{cb}: most accurate determination from the inclusive decays

2% precision limited by theory error

precise Heavy Quarks parameters, tests of OPE

V_{ub}: 7.5% precision shared between experimental and theoretical errors

small rate and large $b \to cl\nu$ background

space cuts to remove $b \to cl\nu$ background which introduce $\mathcal{O}(1)$ dependence on non-preturbative b-quark distribution function

V_{cb} from inclusive semileptonic decays

$$\Gamma_{sl}(b \to c\ell^-\bar{\nu}) = \gamma_{th}|V_{cb}|^2 = \frac{BR(b \to c\ell^-\bar{\nu})}{\tau_b}$$

exp.
$\Delta|V_{cb}| < 1\%$

Γ_{sl} described by Heavy Quark Expansion in $(1/m_b)^n$ and α_s^k

$$\Gamma(B \to X_c l\nu) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2\left[\left[1 + A_{ew}\right]A_{nonpert}A_{pert}\right]$$

non perturbative parameters need to be measured

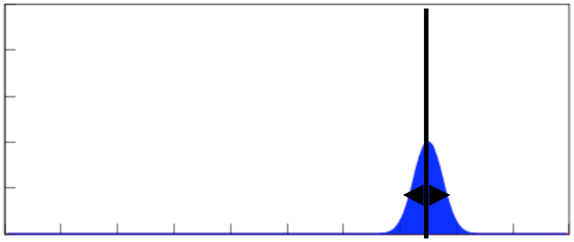
The expansion depend on m_b definition: non-perturbative terms are expansion dependent

Theory error was dominated by $1/m_b^3$ terms and above

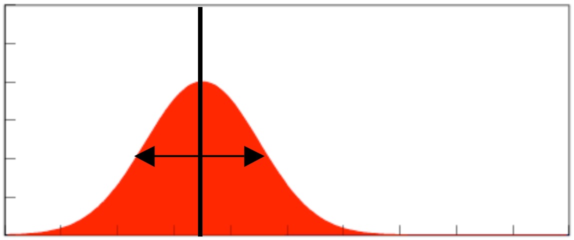
Bc moments in semileptonic decays

X^n are relate to non-perturbative parameters

$$\langle X^n \rangle = \frac{\int (X - X_o)^n \frac{d\Gamma}{dX} dX}{\int \frac{d\Gamma}{dX} dX} = f'_{OPE}(m_b, m_c, \alpha_s)$$



A Distribution

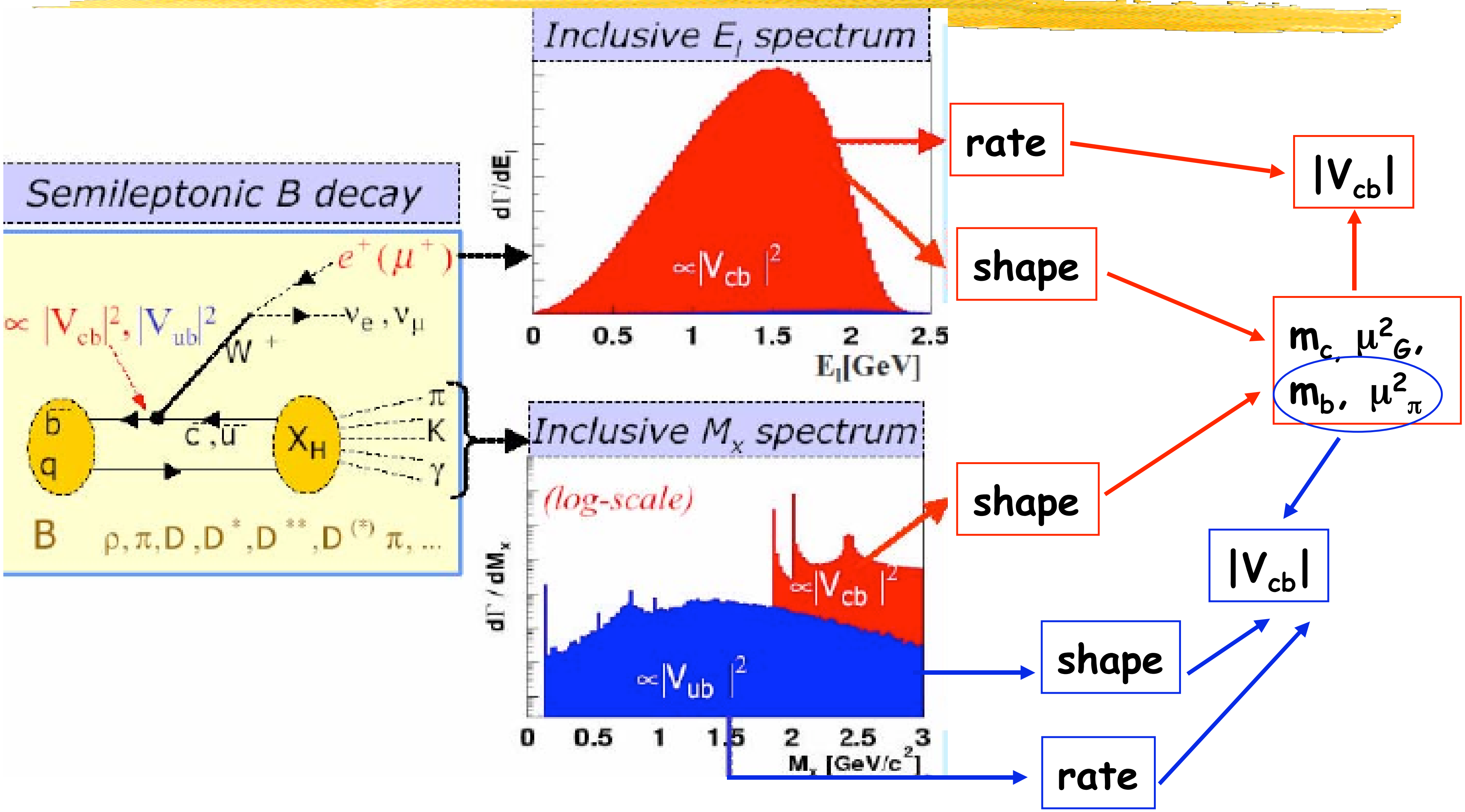


Another Distribution

moments evaluated on the full lepton spectrum or part of it: $p_\ell > p_{min}$ in the B rest frame

higher moments are sensitive to $1/m_b^3$ terms → reduce theory error on V_{cb} and HQ parameters

Inclusive SL decays



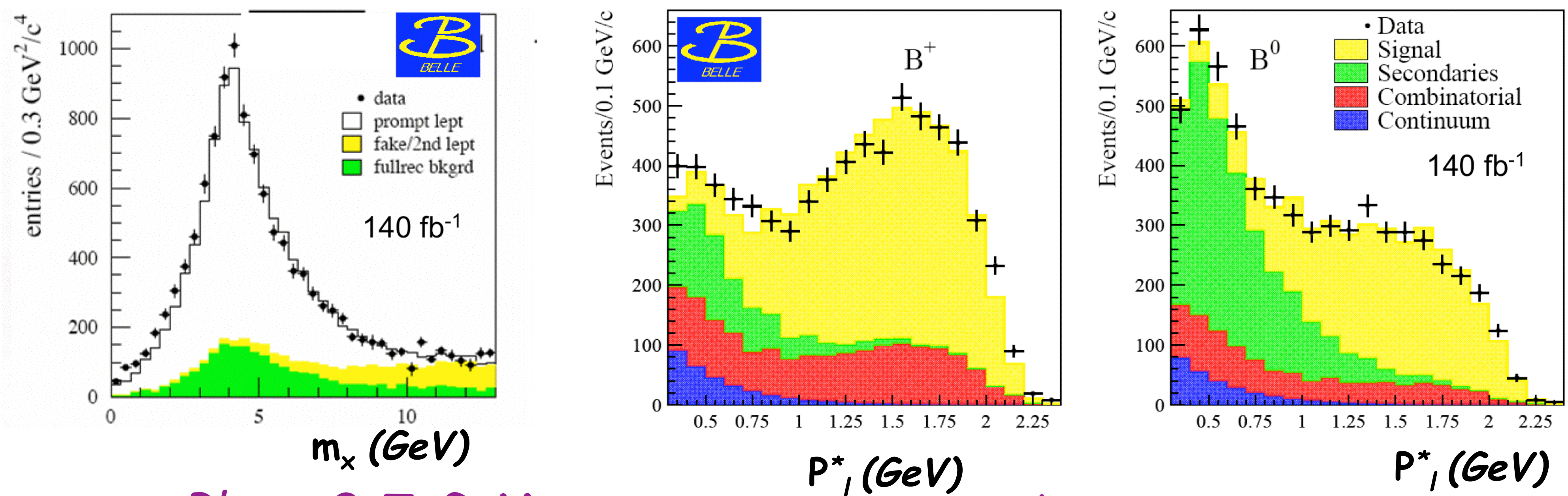
Difficulty to go from measured shape to true shape: e.g. QED corrections, accessible phase space, resolution, background

moments in semileptonic decays

E_ℓ : lepton energy spectrum in $B \to X_c \ell \nu$ (BaBar Belle CLEO Delphi)

$M_X{}^2$: hadronic mass spectrum in $B \to X_c \ell \nu$ (BaBar CDF CLEO Delphi)

Most recent measurements from Belle

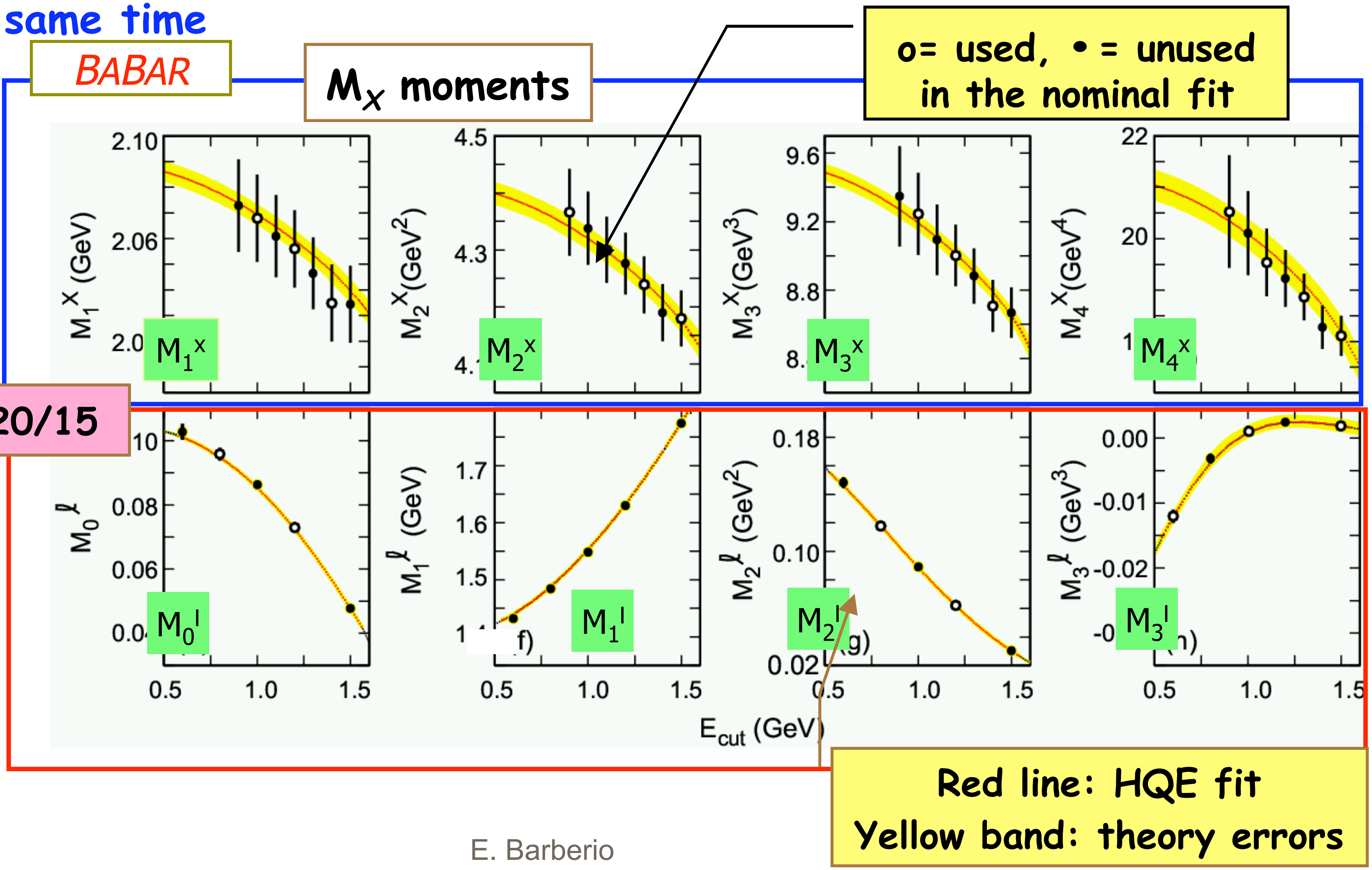


P^l_{min} =0.7 GeV P^l_{min} =0.4 GeV

from the moments of these distributions we get V_{cb} and HQ parameters

Parameters Extraction

BABAR: up to $1/m_b^3$: fit ~90 measurement to extract HQ parameter and V_{cb} at the same time



P.Gambino, N.Uraltsev

hep-ph/0401063
hep-ph/0403166

Vcb and HQ parameters

Global fit Kinetic scheme expansion (hep-ph/0507253)

$$|V_{cb}| = (41.96 \pm 0.23_{exp} \pm 0.35_{HQE} \pm 0.59_{\Gamma SL})10^{-3}$$

δV_{cb} @ 2%

m_b < 1%, m_c @ 5%

			Exp	HQ	Γ_{sl}
$\lvert V_{cb}\rvert$	=	(41.96	± 0.23	± 0.35	± 0.59) 10^{-3}
m_b	=	4.590	± 0.025	± 0.030	GeV
m_c	=	1.142	± 0.037	± 0.045	GeV
μ_π^2	=	0.401	± 0.019	± 0.035	GeV^2
μ_G^2	=	0.297	± 0.024	± 0.046	GeV^2
ρ_D^3	=	0.174	± 0.009	± 0.022	GeV^3
ρ_{LS}^3	=	-0.183	± 0.054	± 0.071	GeV^3
$BR_{cl\nu}$	=	10.71	± 0.10	± 0.08	%

Υ(1S) expansion scheme has similar results

used measurements:

Babar:

- PRD69, 111103 (2004)
- PRD69, 111104 (2004)
- PRD72, 052004 (2005)
- hep-ex/0507001

Belle:

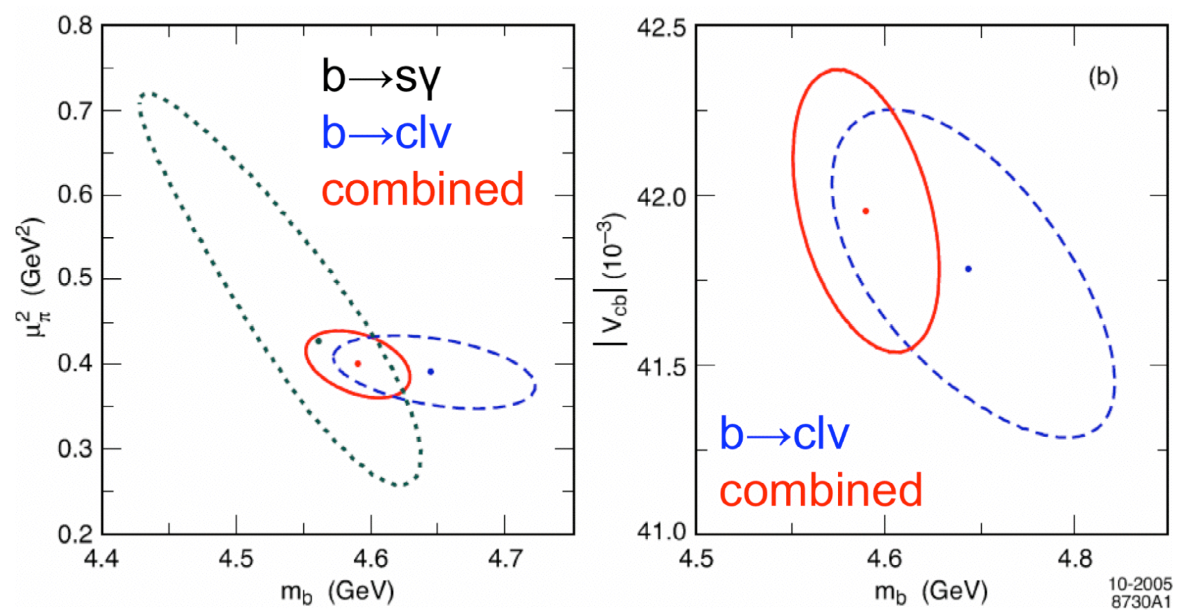
- PRL93, 061803 (2004)
- hep-ex/0508005

CLEO:

- PRD70, 032002 (2004)
- PRL87, 251807 (2001)

CDF: PRD71, 051103 (2005)

DELPHI: EPJ C45, 35 (2006)



V_{ub} inclusive determination

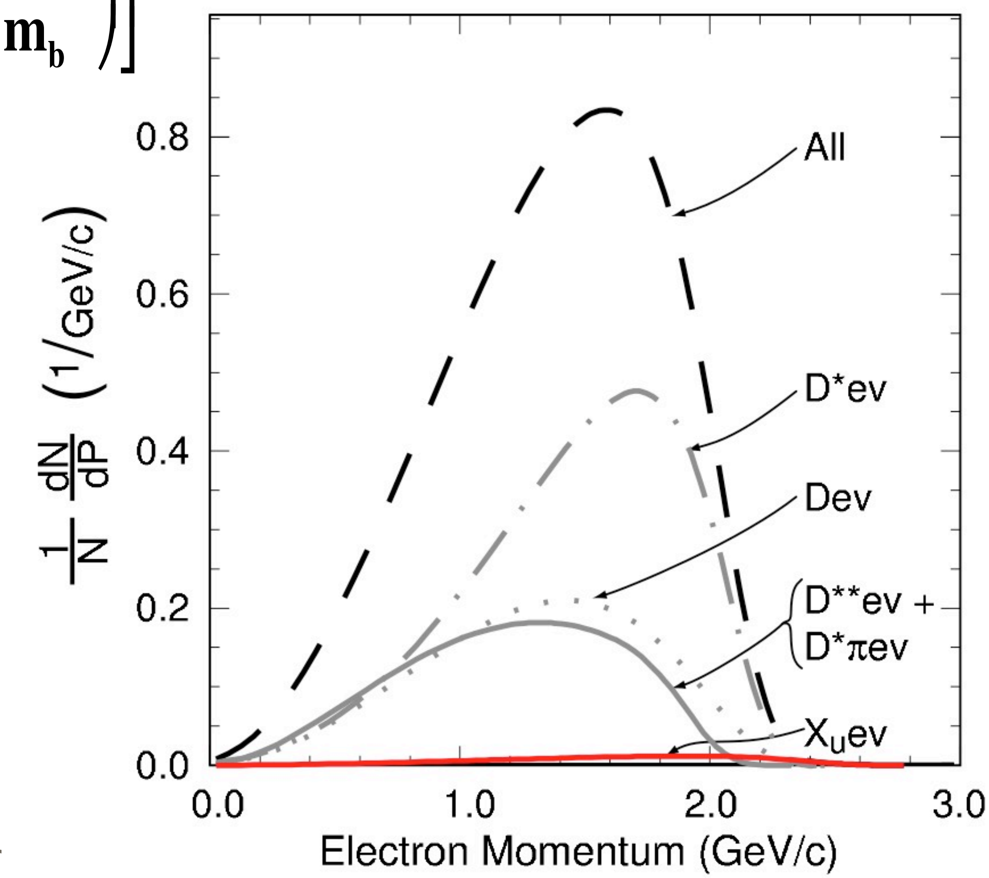
$B \rightarrow X_u l\nu$ rate tree level from OPE → corrected for perturbative α_s and non-perturbative $1/m_b$ terms

$$\frac{d\Gamma(B \rightarrow X_u l \nu)}{d(\text{p.s.})} \sim \frac{m_b^5 G_F^2}{192\,\pi^3}\left[\text{parton model} + \sum_n C_n \left(\frac{\Lambda_{QCD}}{m_b}\right)\right]$$

In principle main uncertainty from m_b^5

BUT…..

$Br(B \rightarrow X_u l\nu)/Br(B \rightarrow X_c l\nu) = 1/50$

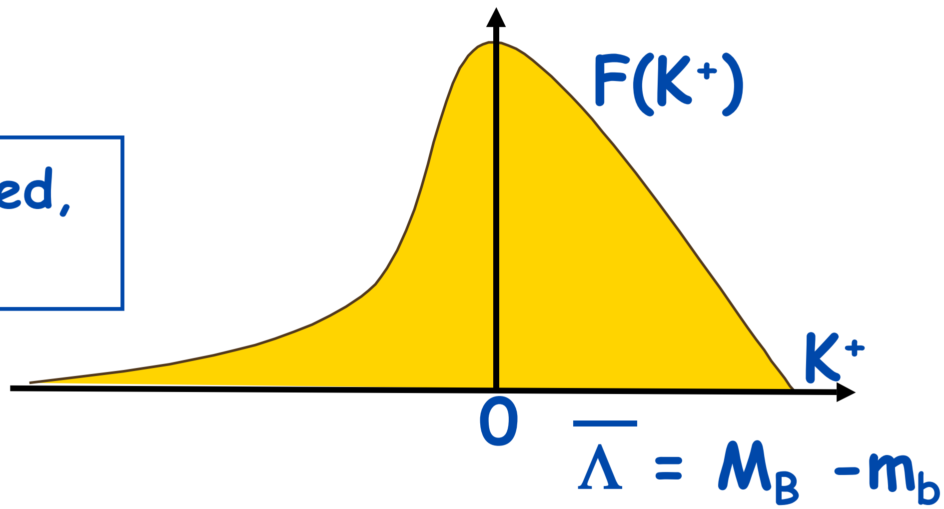


Shape Function

Limited phase space to reduce the $B \to X_c l\nu$ background:

OPE doesn't work everywhere in the phase space → non-perturbative Shape Function $F(K^+)$ to extrapolate to the full phase space

Detailed shape not constrained, in particular the low tail

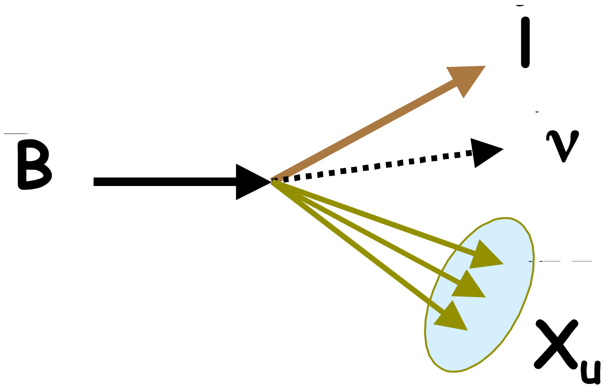


Mean and r.m.s. are known

Shape Function need to be determined from experimental data

Inclusive $B \to X_u l\nu$

$m_u << m_c$ → exploits different kinematics



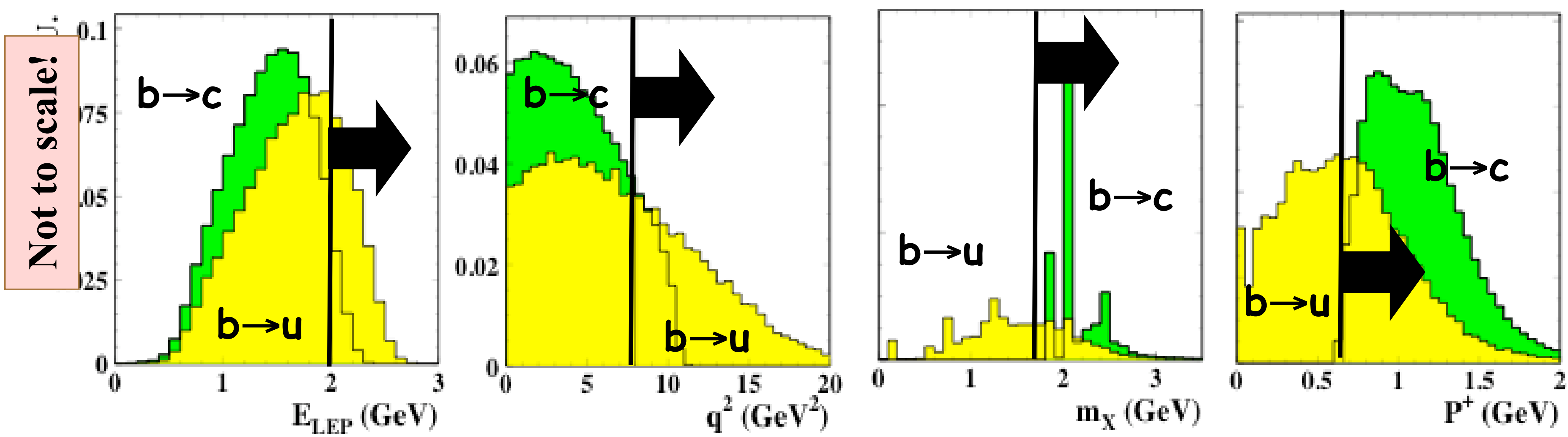
E_l = lepton energy

q^2 = lepton-neutrino mass squared

m_X = hadron system mass

$P^+ = E_X - |P_X|$

Signal events have smaller M_X and P_+ → Larger E_l and q^2



Lepton Endpoint

BABAR PRD 73:12006
Belle PLB 621:28
CLEO PRL 88:231803

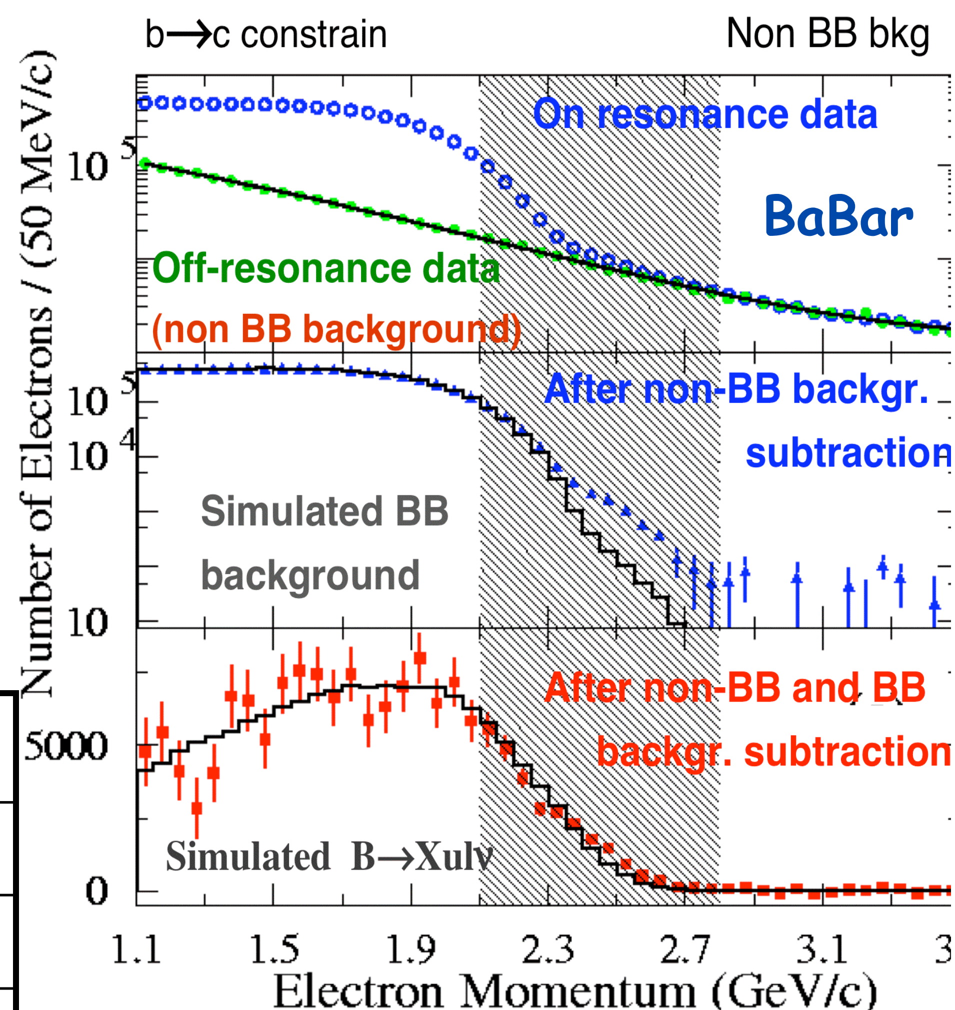
First measurement from CLEO $E_l > 2.3$ GeV

BaBar $E_l > 2.0$ GeV

Belle $E_l > 1.9$ GeV

Crucial accurate subtraction of background is crucial!

S/B ~1/10 eff~ 40%



	ΔB (10^{-4})
BABAR 80fb^{-1}	$5.72 \pm 0.41_{stat} \pm 0.65_{sys}$
Belle 27fb^{-1}	$8.47 \pm 0.37_{stat} \pm 1.53_{sys}$
CLEO 9fb^{-1}	$2.30 \pm 0.15_{stat} \pm 0.35_{sys}$

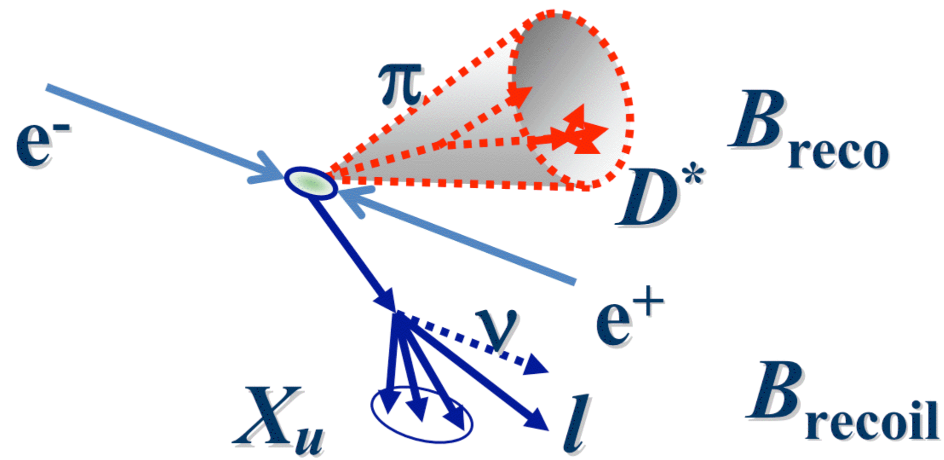
Measuring m_X q^2 P^+

BABAR hep-ex/0507017
Belle PRL 95:241801

Reconstruct all decay products to measure M_X, q^2 or P^+

fully-reconstructed B meson

- flavor and momentum known



lepton in the recoil-B

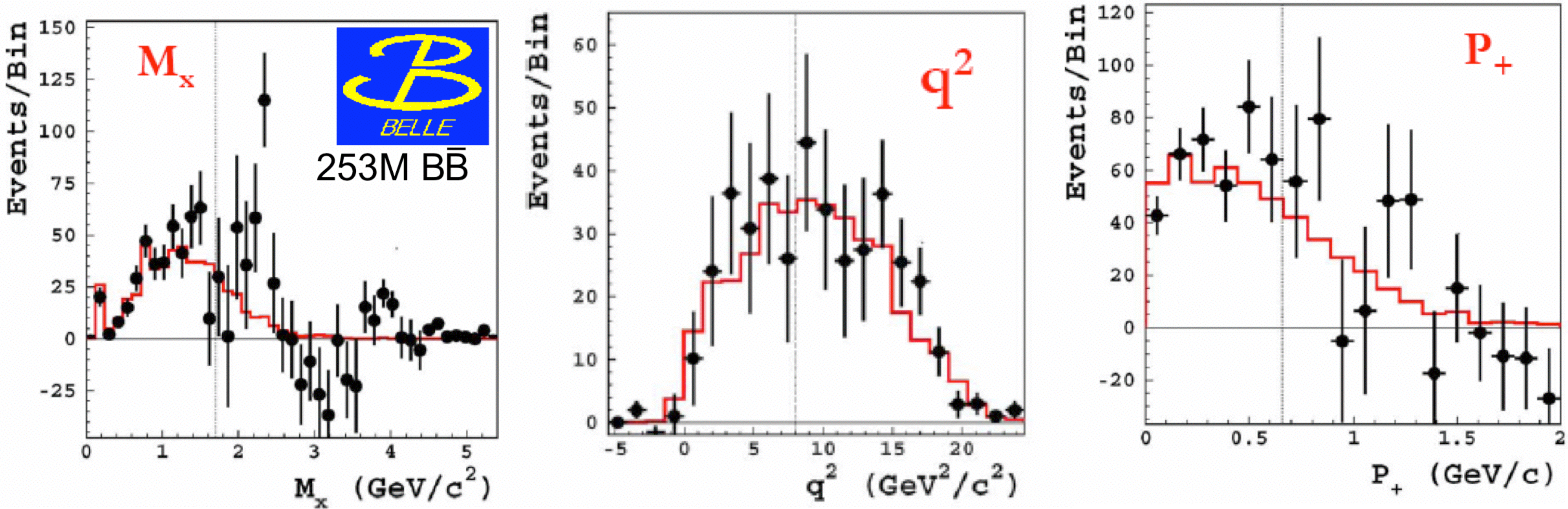
- m_{miss} consistent with a neutrino
- lepton charge consistent with B flavor

S/B ~ 2 Eff~ 0.1%

left-over particles belong to X

- equal m_B on both sides; m_{miss} = 0

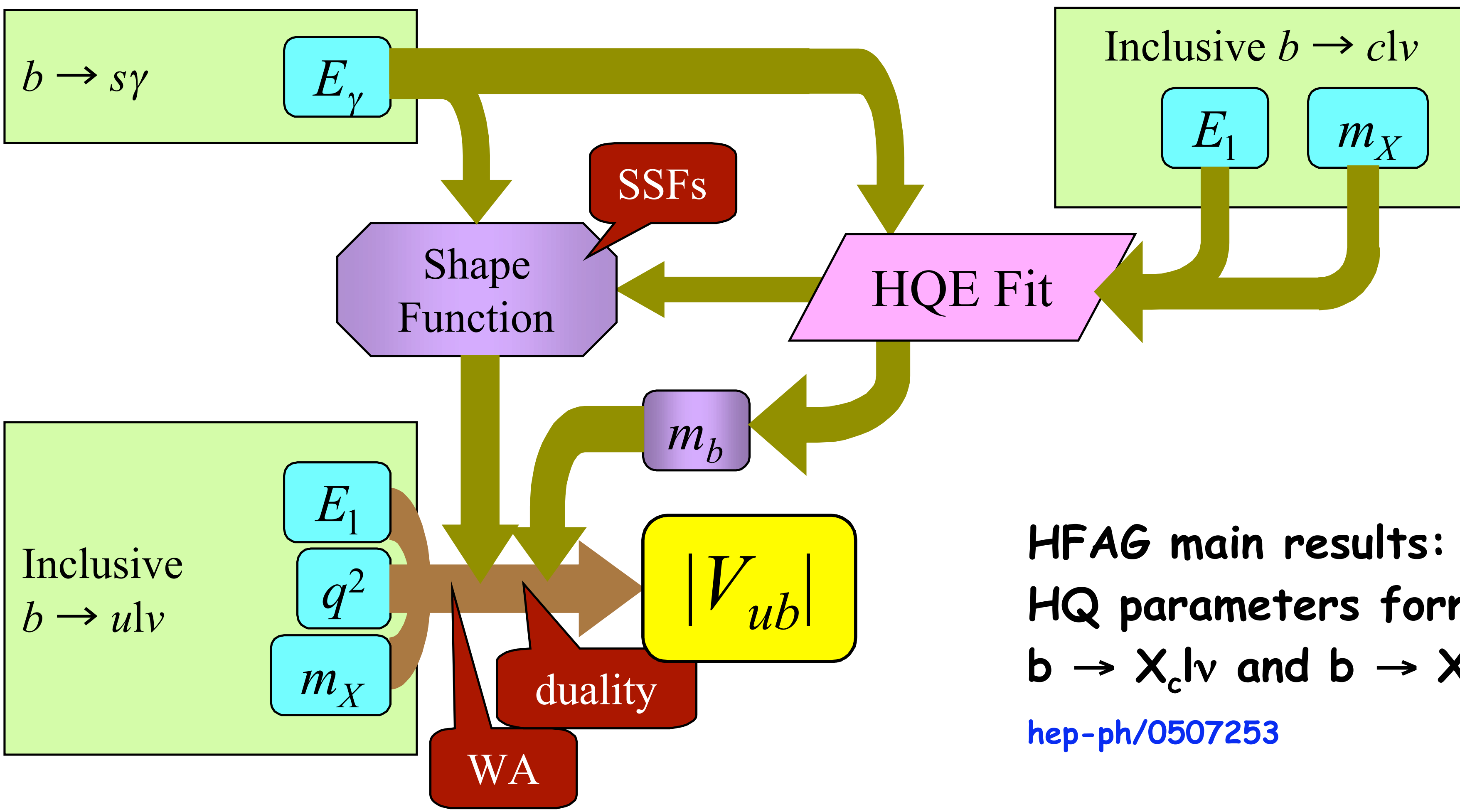
Measuring Partial Branching Fraction



P_+ BLNP PRL93:221802

		$\Delta\mathcal{B}$ (10^{-4})
BABAR 211fb^{-1}	$m_X < 1.7,\ q^2 > 8$	$8.7 \pm 0.9_{stat} \pm 0.9_{sys}$
Belle 253fb^{-1}	$m_X < 1.7$	$12.4 \pm 1.1_{stat} \pm 1.0_{sys}$
first measurement	$m_X < 1.7,\ q^2 > 8$	$8.4 \pm 0.8_{stat} \pm 1.0_{sys}$
of P_+ spectrum	$P_+ < 0.66$	$11.0 \pm 1.0_{stat} \pm 1.6_{sys}$

Turning ΔB into $|V_{ub}|$



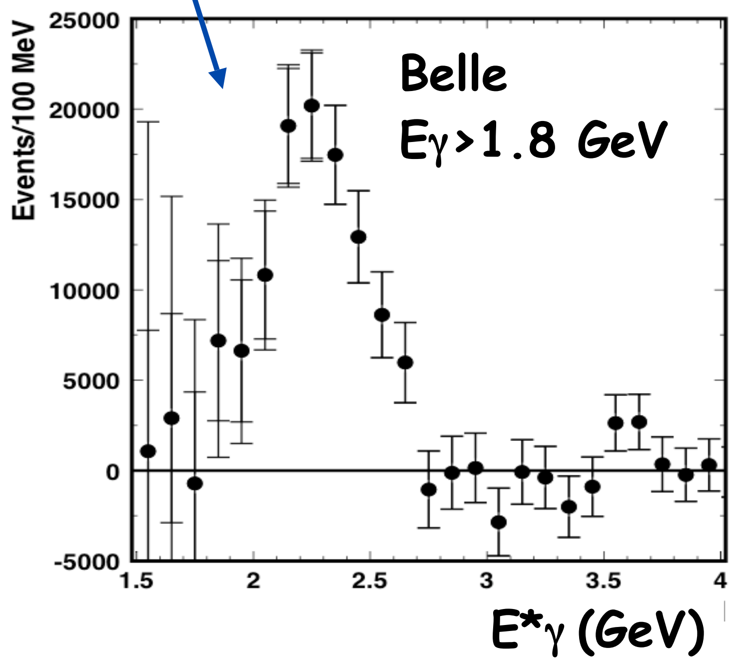
HFAG main results:
HQ parameters form
b → $X_c l\nu$ and b → $X_s\gamma$

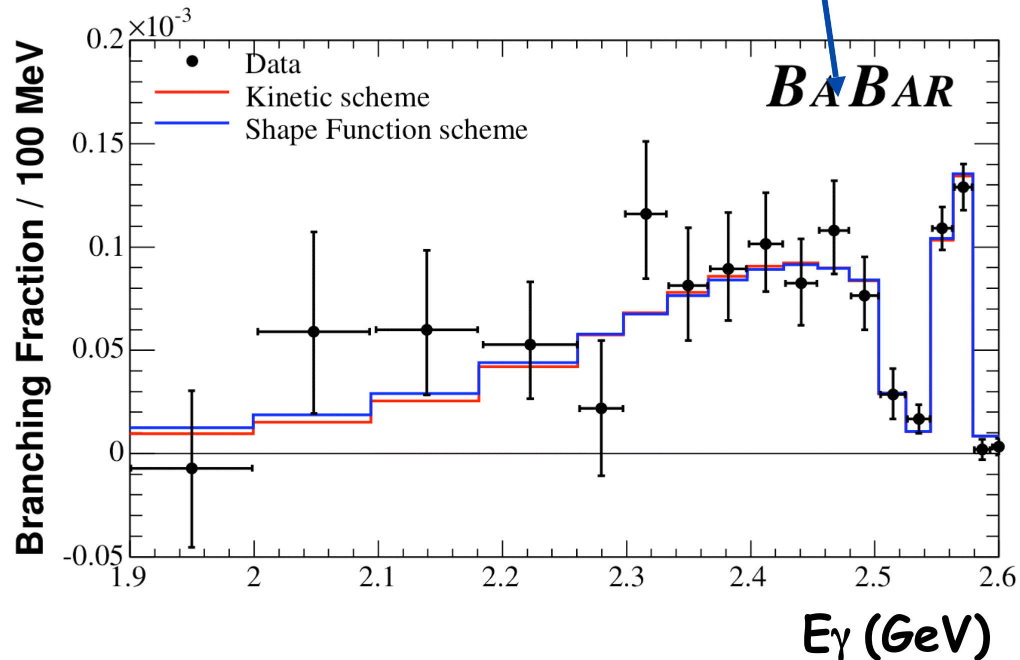
hep-ph/0507253

Dealing with Shape Function

easy to fit shape function

Better resolution → K* peak (more difficult for SF)

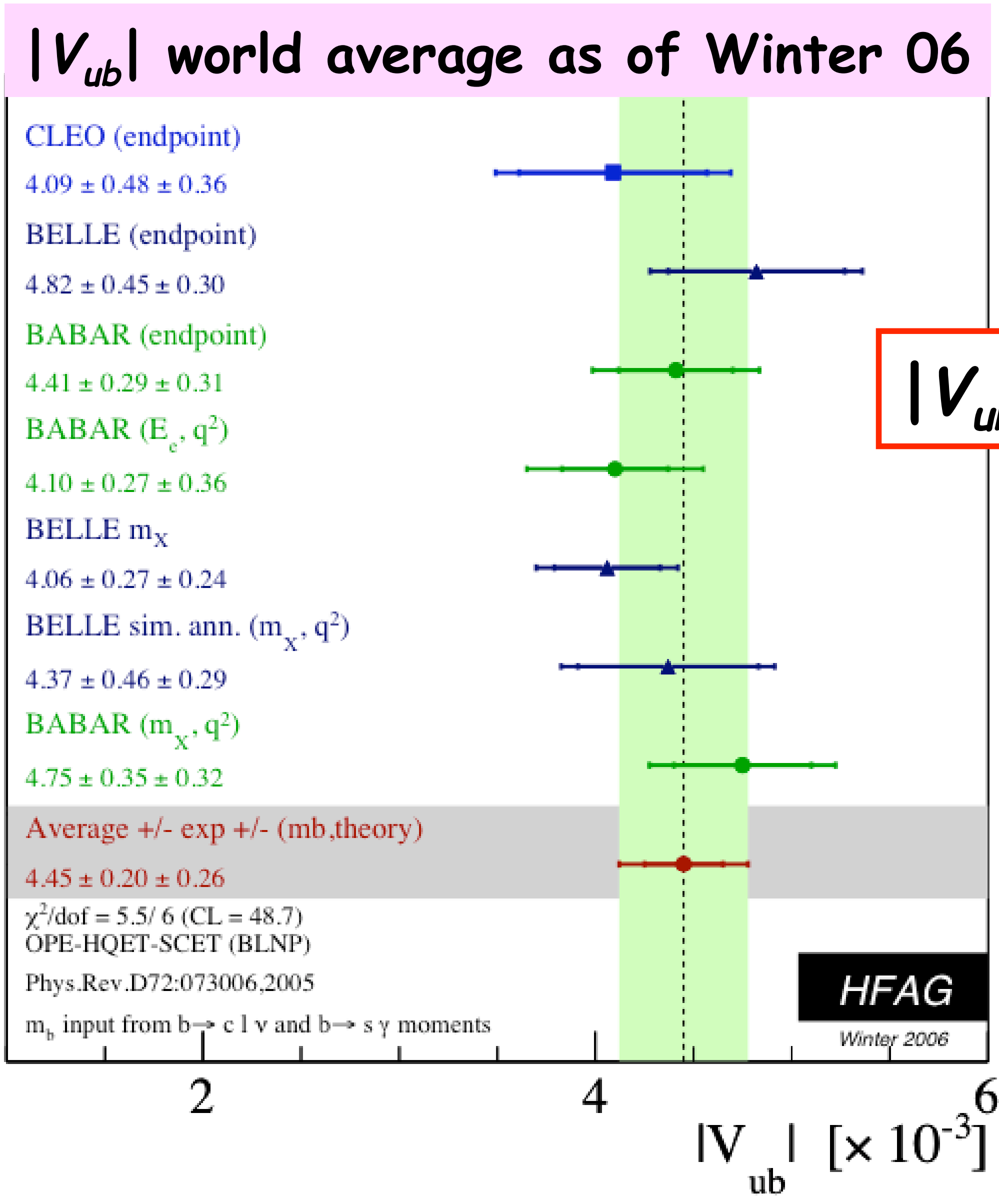




Solution → use directly the γ spectrum:

$$\int^{x_i^{cut}} dx \frac{d\Gamma(B\to X_u l\bar{\nu})}{dx_i} = \int dE_\gamma \underbrace{W(x_i^{cut}, E_\gamma)}_{\text{theory}} \frac{d\Gamma(B\to X_s\gamma)}{dE_\gamma}$$

Inclusive $|V_{ub}|$: BLNP framework



Inputs:

$m_b(SF) = 4.60 \pm 0.04$ GeV

$\mu_\pi^2(SF) = 0.20 \pm 0.04$ GeV^2

$$|V_{ub}|^{BLNP} = (4.45 \pm 0.20 \pm 0.26)\ 10^{-3}$$

$\delta|V_{ub}| = \pm 7.3\%$

Statistical	±2.2%
Expt. syst.	±2.7%
$B \to X_c l\nu$ model	±1.9%
$B \to X_u l\nu$ model	±2.1%
Subleading SF	±3.8%
other theory error	±4.5%

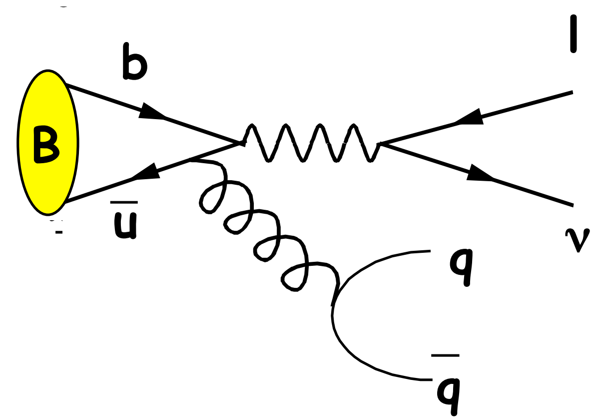
Theory Errors

Quark-hadron duality is not considered (cut dependent)

- $b \to cl\nu$ and $b \to s\gamma$ data fit well HQ predictions

Weak annihilation ➔ ± 1.9% error

- Expected to be <2% of the total rate
- $\Gamma_{w.a.}/\Gamma(b \to u)$ < 7.4 % from CLEO



HQ parameters ➔ ± 4.1% mainly m_b; kinematics cuts depend on m_b!

Sub-leading shape function ➔ ± 3.8% dominated by the lepton endpoint measurements

Inclusive $|V_{ub}|$: DGE framework

Dressed Gluon Exponentiation (DGE)

on-shell b-quark calculation converted into hadronic variables used as approximation to the meson decay spectrum

$$|V_{ub}|^{DGE} = (4.41 \pm 0.20 \pm 0.20)\ 10^{-3}$$

Still digesting the method

DGE theory ➔ ±2.9% matching scheme method and scale

m_b(MS) ➔ ± 1.3% on event fraction $m_b(MS)=4.20\pm0.04$ GeV

α_s ➔ ± 1.0% on event fraction

total Γ_{SL} ➔ ± 3.0 %

V_{ub} without Shape Function

Babar

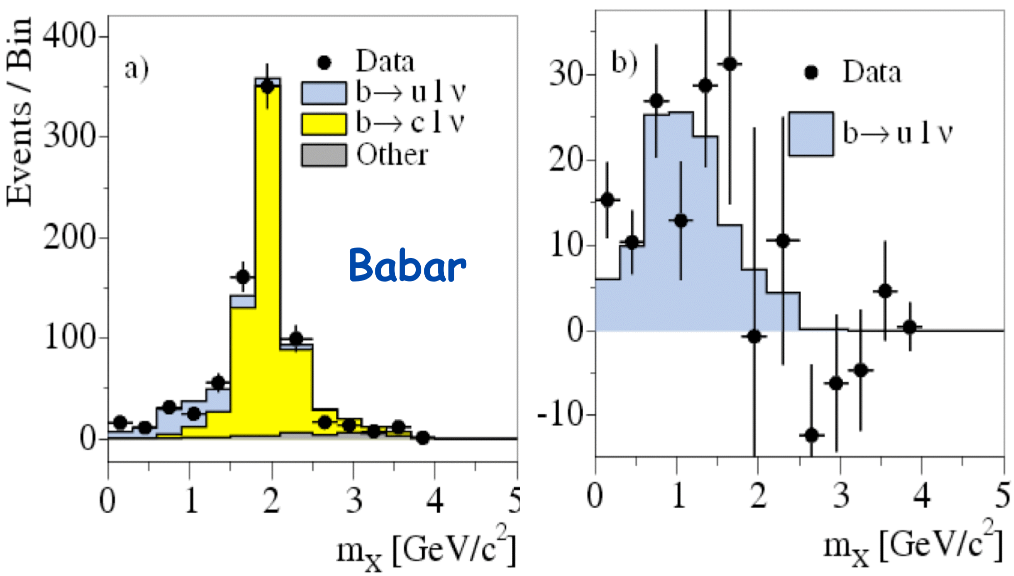
Based on Leibovich, Low, Rothstein, PLB 486:86

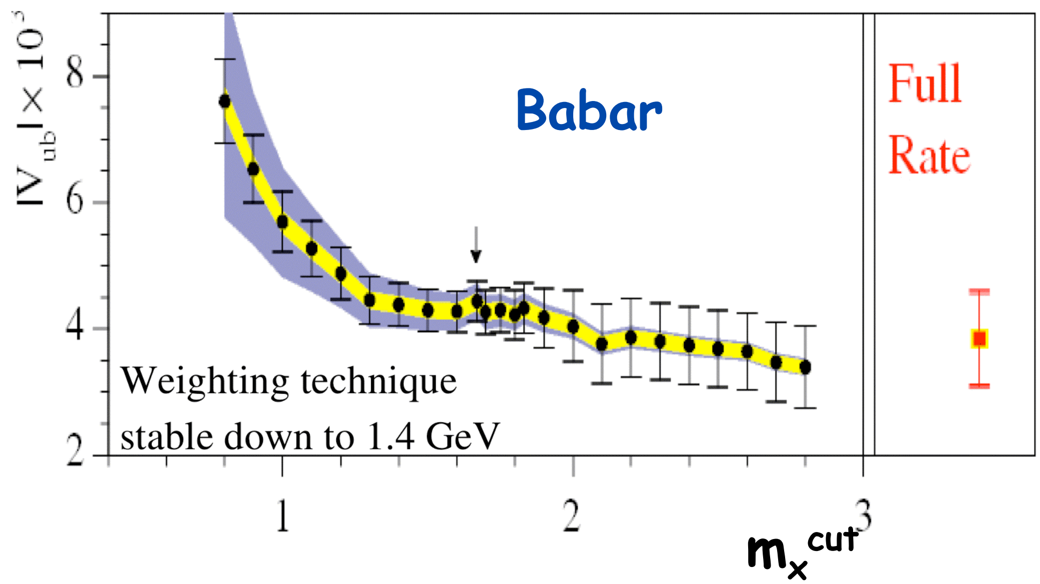
First proposal by Neubert

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

$$|V_{ts}| \sim |V_{cb}| + O(1)$$

Weight function





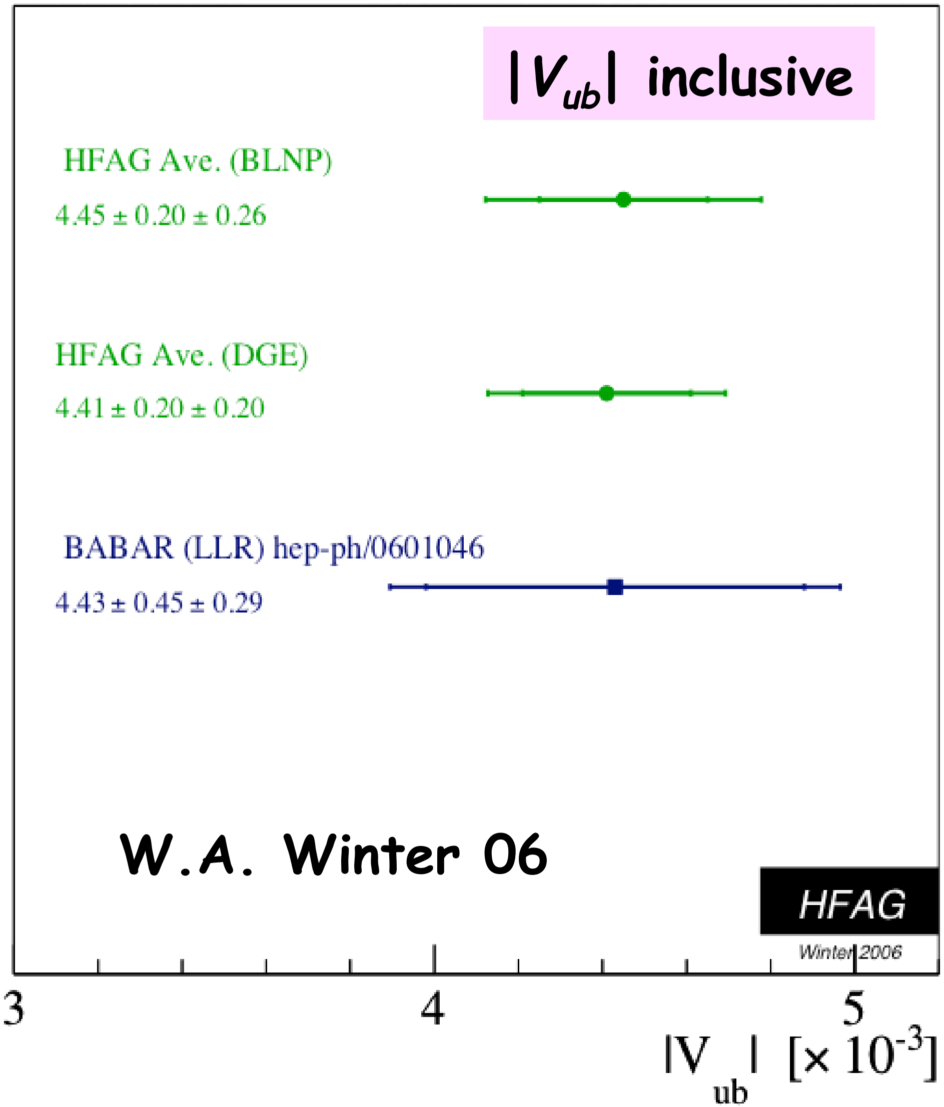
OPE m_x<2.50 GeV

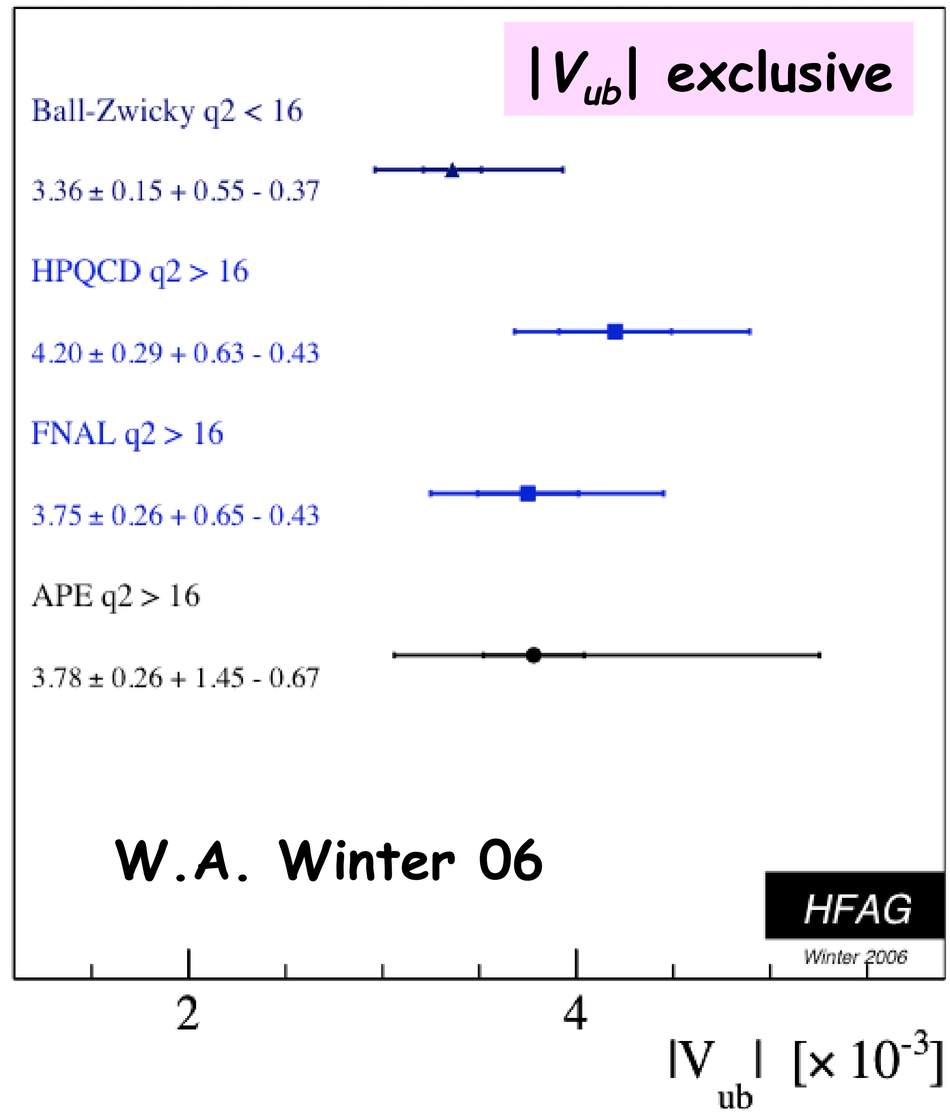
$$|V_{ub}| = (3.38\pm0.70_{stat}\pm0.30_{sys}\pm0.10_{theo})10^{-3}$$

LLR m_x<1.67 GeV

$$|V_{ub}| = (4.43\pm0.30_{stat}\pm0.25_{sys}\pm0.29_{theo})10^{-}$$

$|V_{ub}|$: inclusive vs exclusive





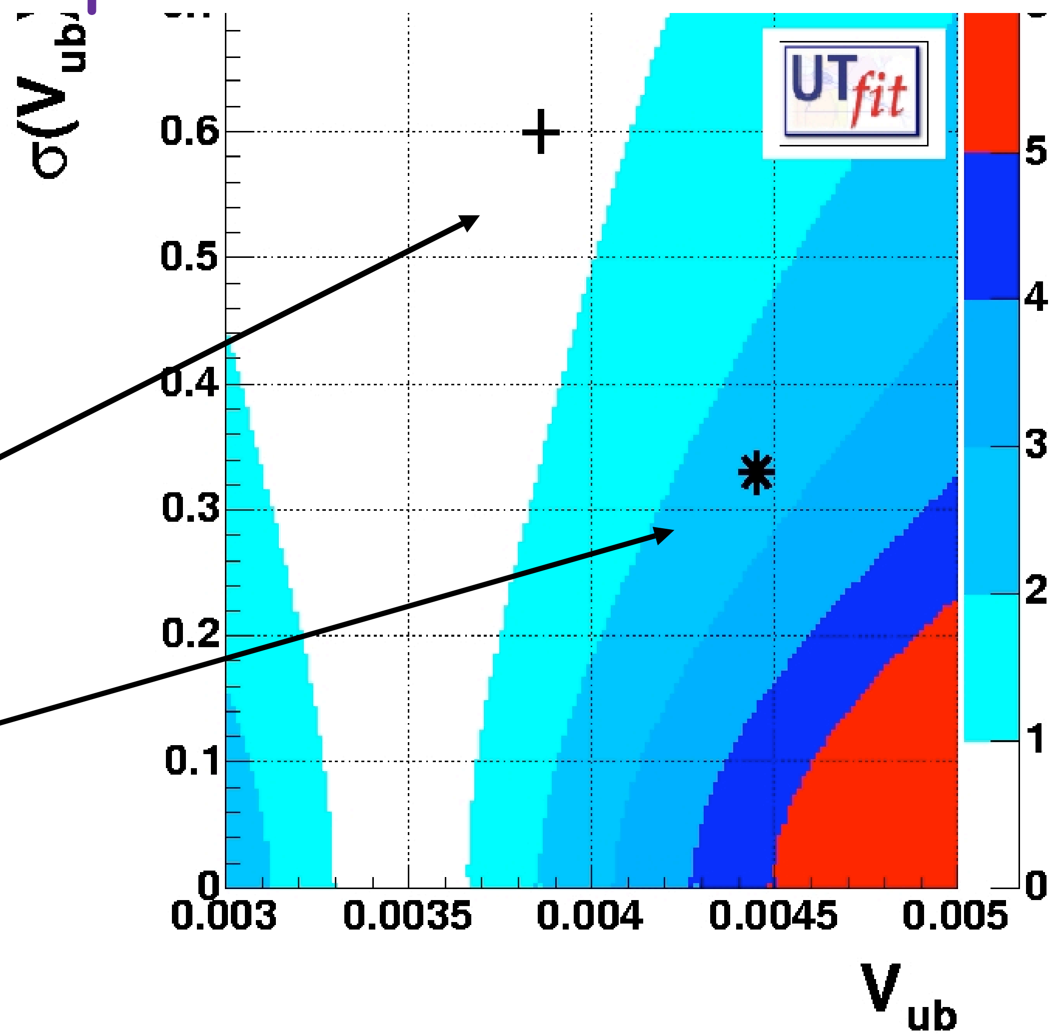
$|V_{ub}|$: CKM consistency

Most probable value of V_{ub} from measurements of other CKM parameters Standard Model predictions with Δms measurement

(thank to Pierini)

V_{ub} from exclusive measurements

V_{ub} from inclusive measurements



Conclusions

$b \to c l \nu$

V_{cb} 2% error dominated by theory, m_b @1% (kinetic and $\Upsilon(1S)$ schemes), m_c @5% (kinetic scheme)

but how well do we know the $B \to X_c l \nu$ spectrum?

$b \to u l \nu$

V_{ub} ~7.4% error shared between theoretical and experimental

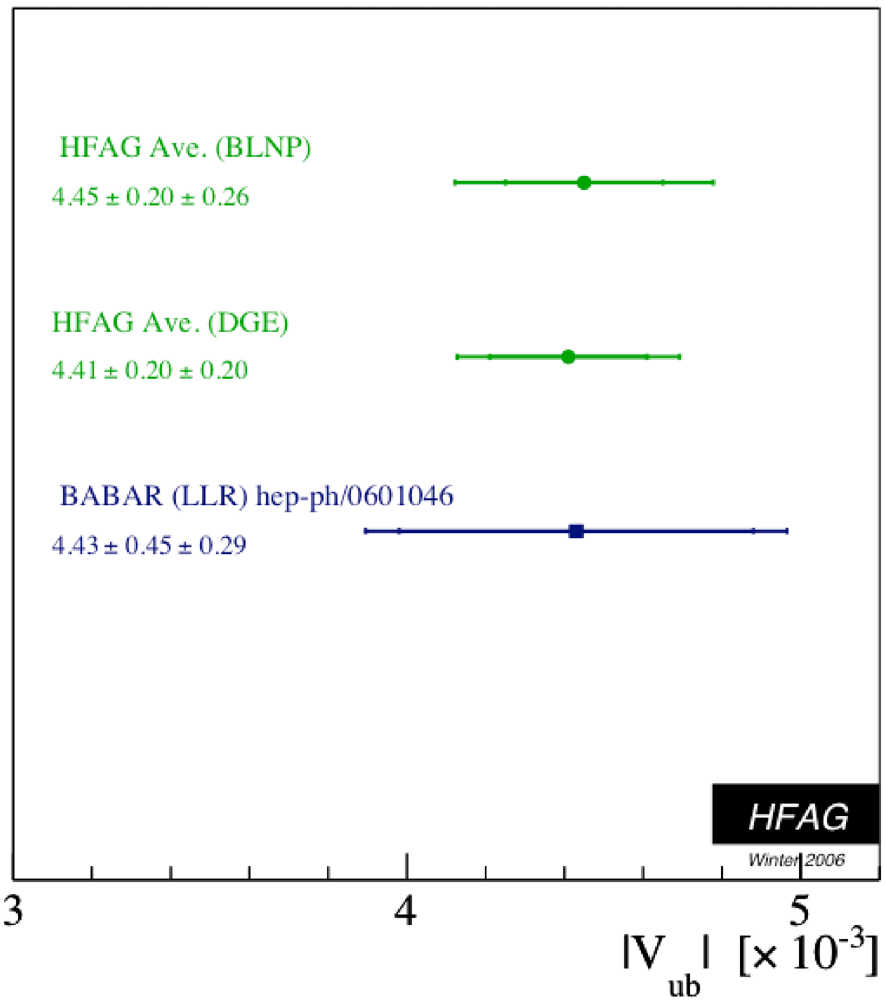
inclusive vs exclusive less than 1.4 σ difference, depending on the inclusive extracting method

We have now different methods to extract V_{ub}

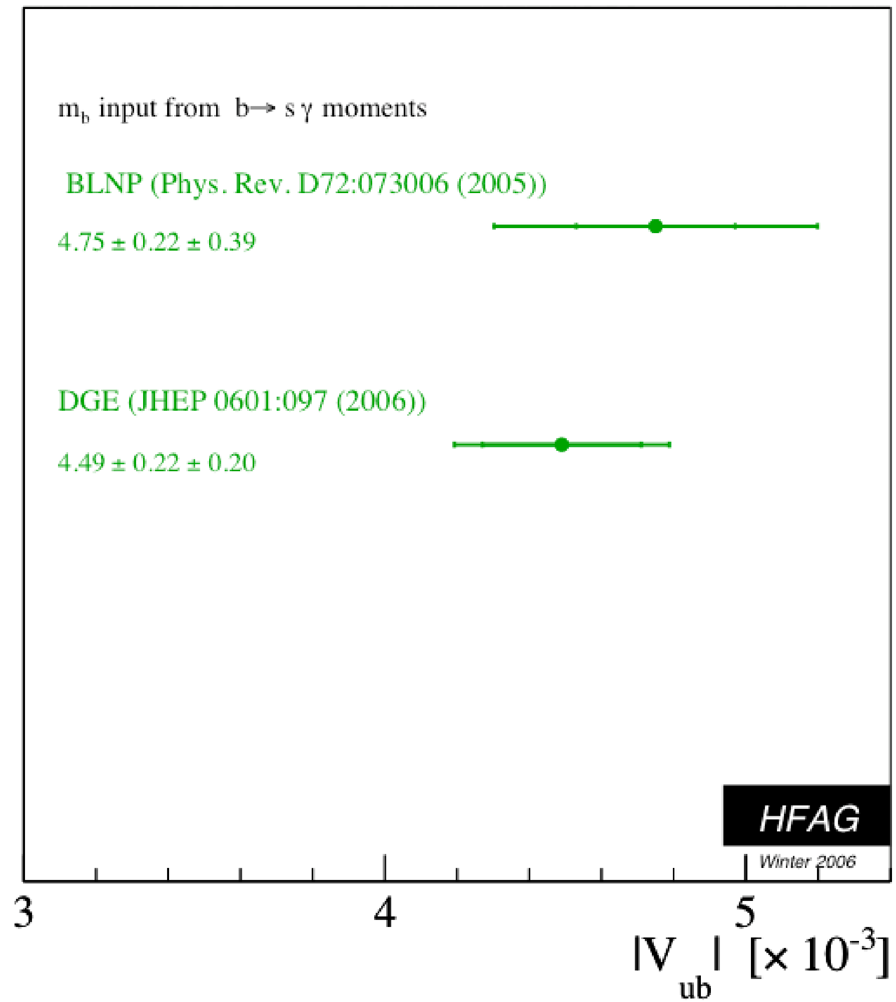
$|V_{ub}|$ @ 5% possible? Improve knowledge of $B \to X_c l \nu$, $B \to X_u l \nu$ and more work on the theoretical error

Inclusive $|V_{ub}|$: comparisons

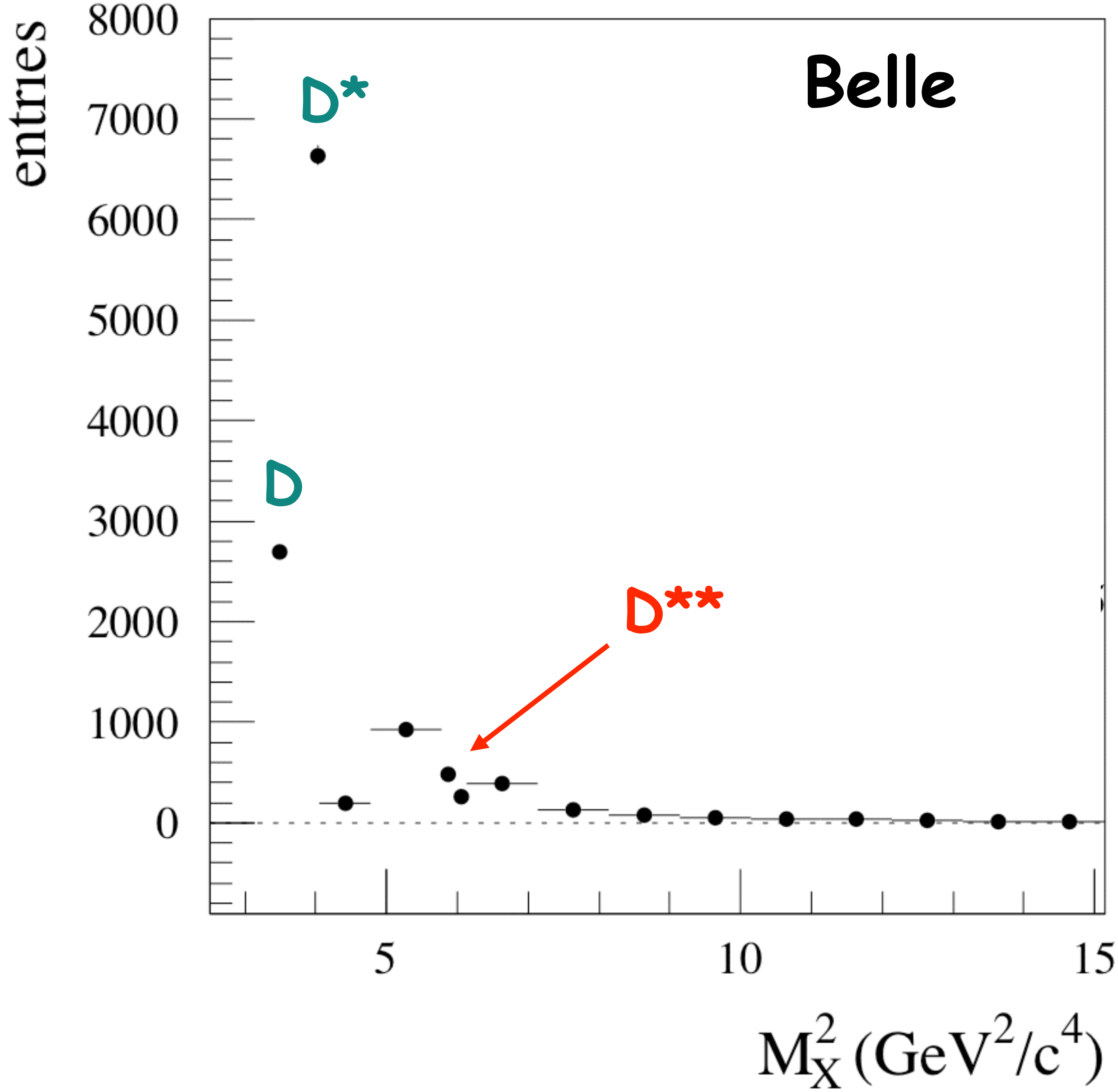
HQ parameters from clν and sg



HQ parameters from sg only

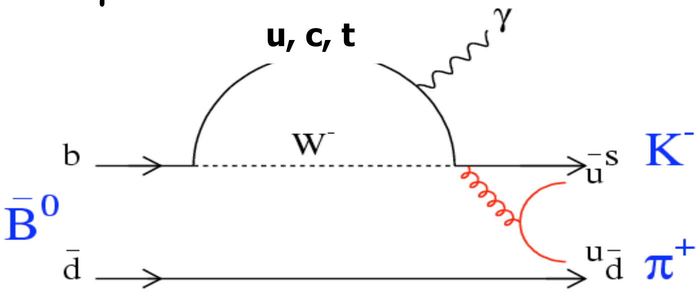


M_x unfolded spectrum for $B \to X_c\, l\, \nu$



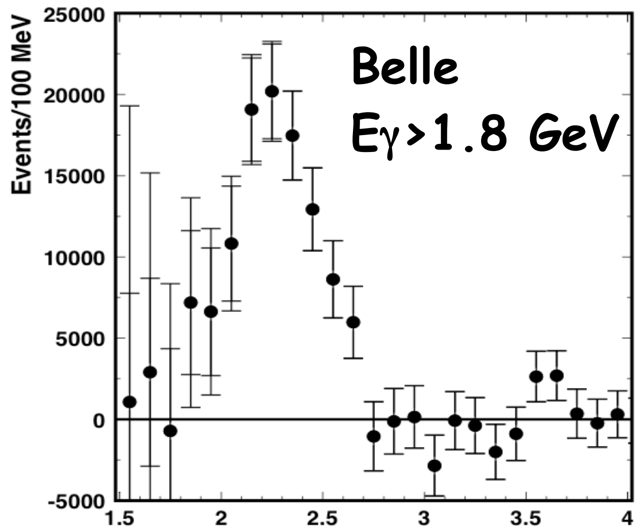
photon energy spectrum

E_γ : photon energy spectrum in $B \to s\gamma$ (BaBar Belle CLEO Delphi)



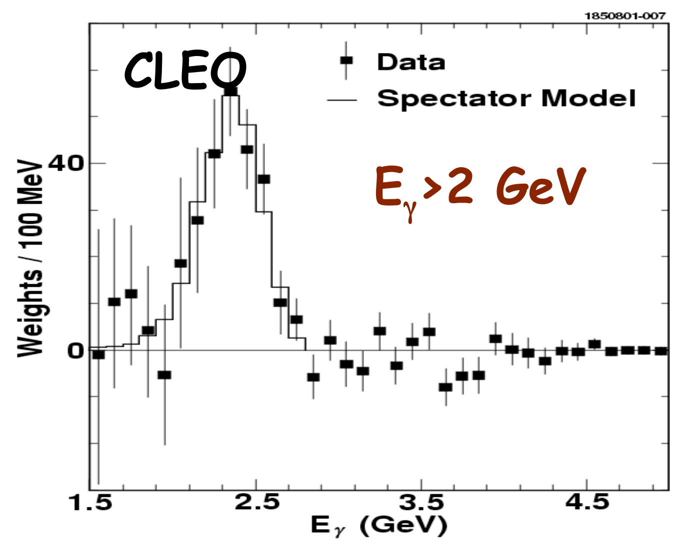
photon energy spectrum in $B \to X_\sigma \gamma$ not sensitive to new physics and give information on B structure

$$\langle E_\gamma \rangle = m_b + \ldots \quad var\langle E_\gamma \rangle = \mu_\pi^2 / 12 + \ldots$$



$$m_b(1GeV) = 4.62\ GeV$$

$$\mu_\pi^2(1GeV) = 0.40\ GeV^2$$



$$m_b(1GeV) = 4.66 \pm 0.067\ GeV$$

$$\mu_\pi^2(1GeV) = 0.477 \pm 0.052\ GeV^2$$