The Quest for New Physics at CLEO

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DESY Seminar

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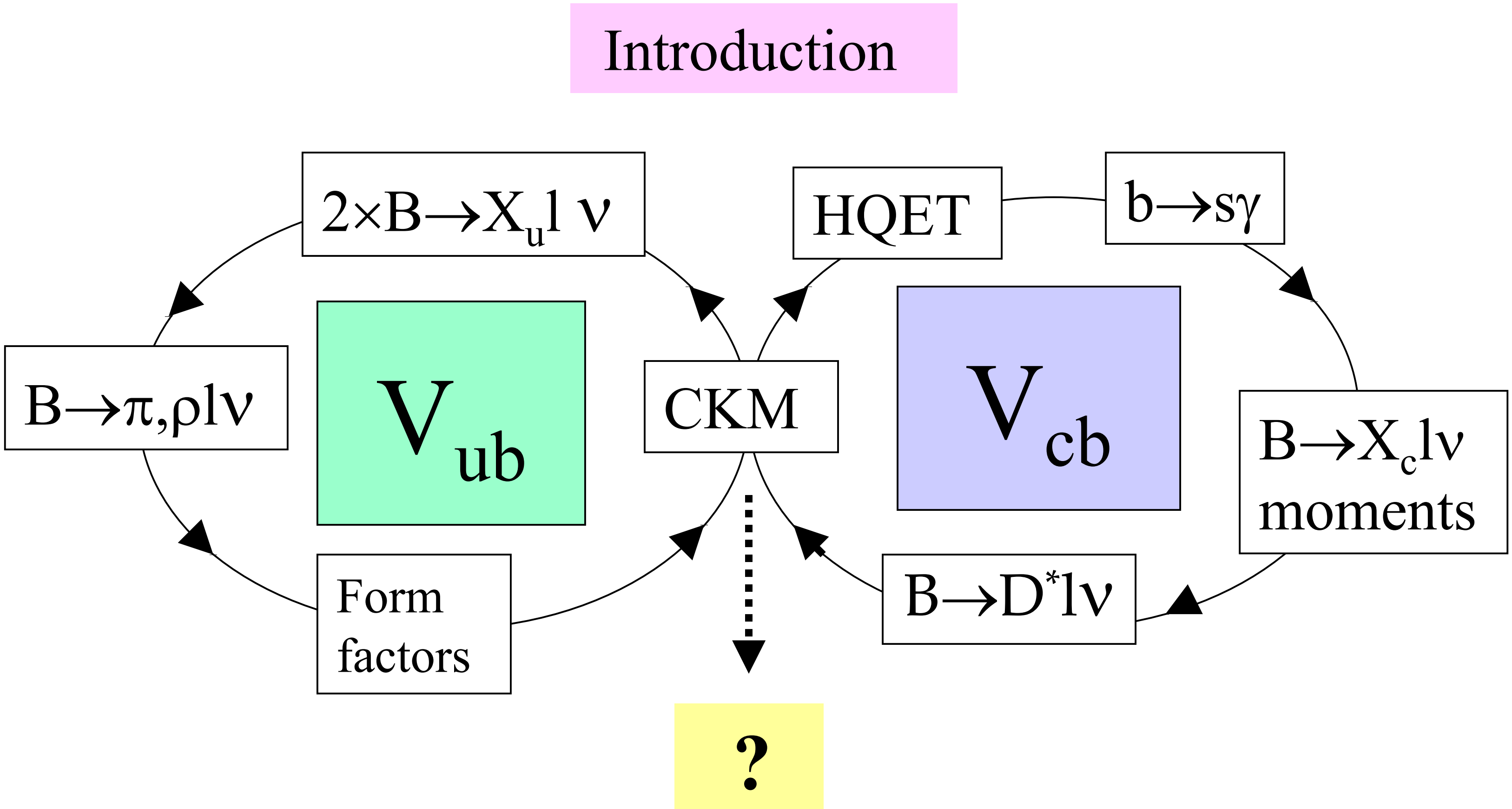
Narrowing the CKM constraints from $|V_{cb}|$ and $|V_{ub}|$: A Roadmap



CKM matrix

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

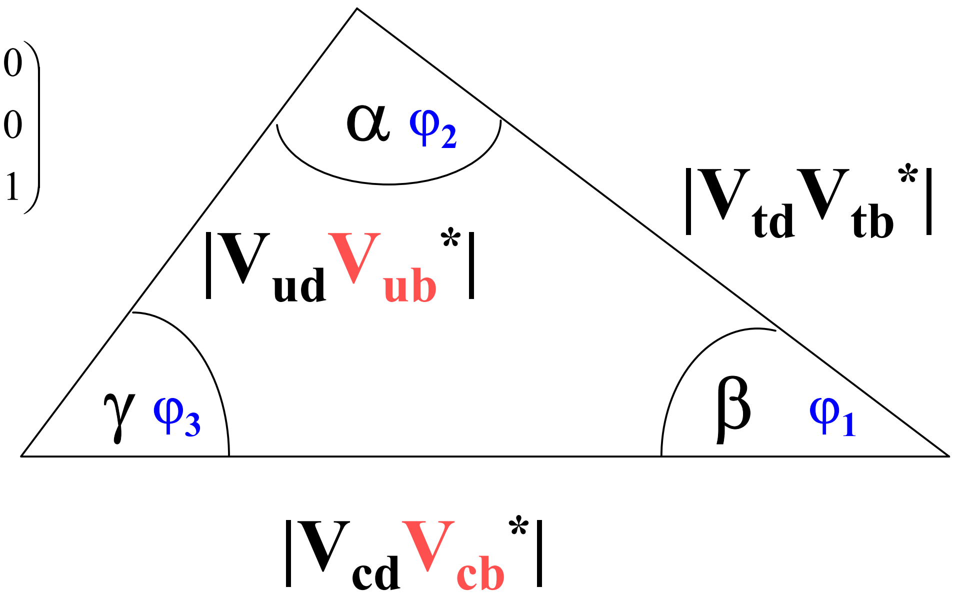
- Connects mass and weak eigenstates
- Each V_{ij} has real and imaginary parts, move imaginary phase into V_{ub} and V_{td}
- **Elements are model parameters that have to be measured**
- $V^{\dagger}V=1$ gives six triangles for the off-diagonal elements

This talk is mostly about $|V_{cb}|$ and $|V_{ub}|$ obtained by studying semileptonic decays.

An example unitarity triangle:

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

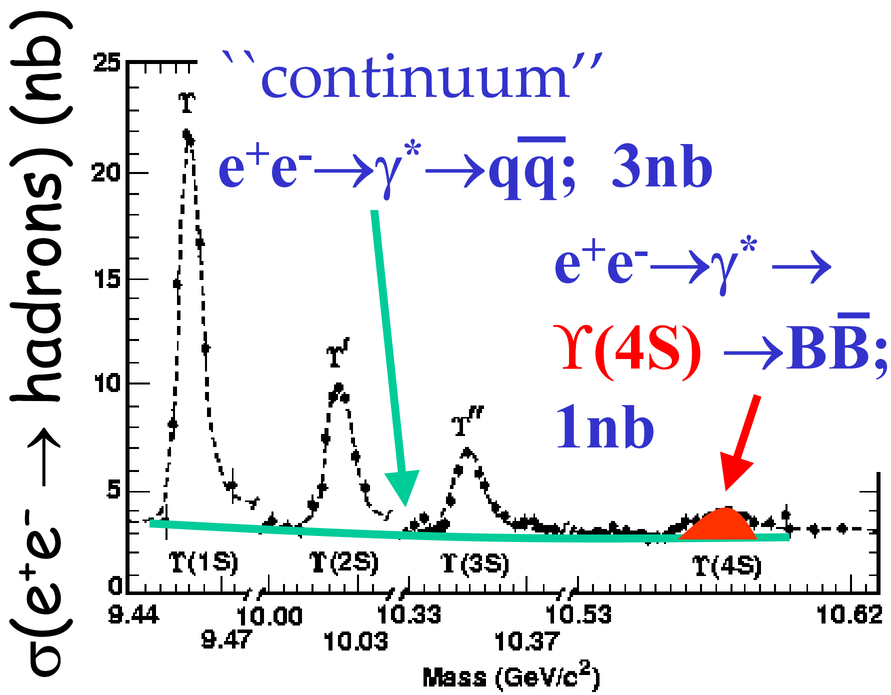
$$\begin{pmatrix} \bullet & \circ & \cdot \\ \circ & \bullet & \circ \\ V_{ub} & V_{cb} & V_{tb} \end{pmatrix}^* \times \begin{pmatrix} V_{ud} & \circ & \cdot \\ V_{cd} & \bullet & \circ \\ V_{td} & \circ & \bullet \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

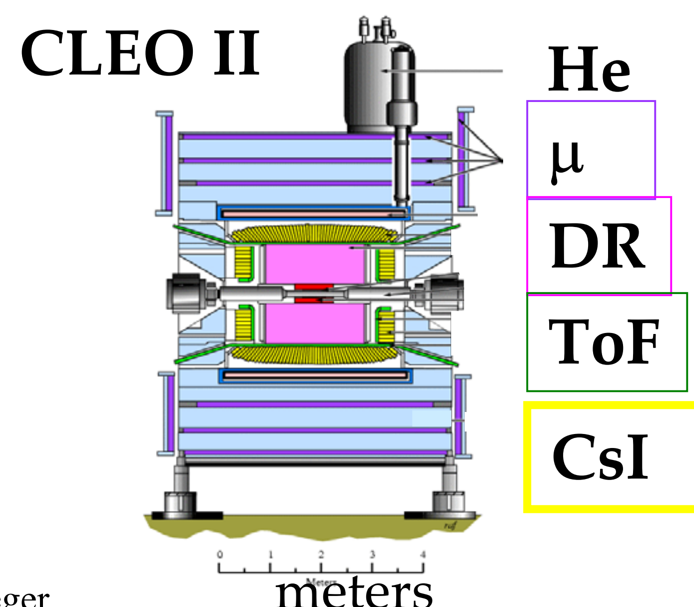


- V_{ub} measures one side, sin2β one angle
- **Want to overconstrain to look for new physics**

B physics at the CLEO detector

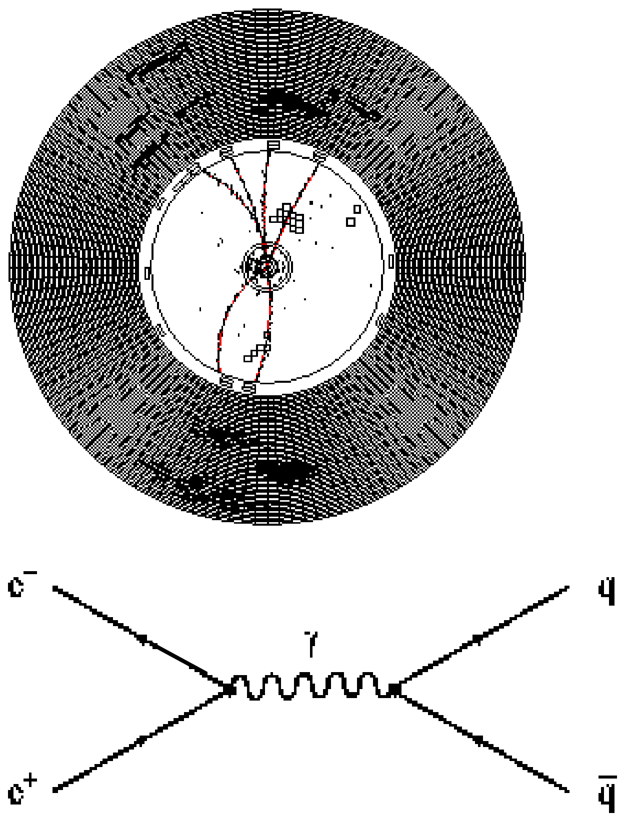
- CESR accelerator operates ON the $\Upsilon(4S)$ resonance (10.58GeV), just above B pair production threshold $\rightarrow$ at rest, very clean
- Parts of data taken 60MeV below resonance (OFF) to aid in background subtraction
- Datasets:
  – CleoII(.V): 9.1fb^{-1}ON $\Upsilon(4S)$ (10M BB), 4.4fb^{-1}OFF
  – CleoIII: 6.9fb^{-1}ON $\Upsilon(4S)$ (7M BB), 2.3fb^{-1}OFF

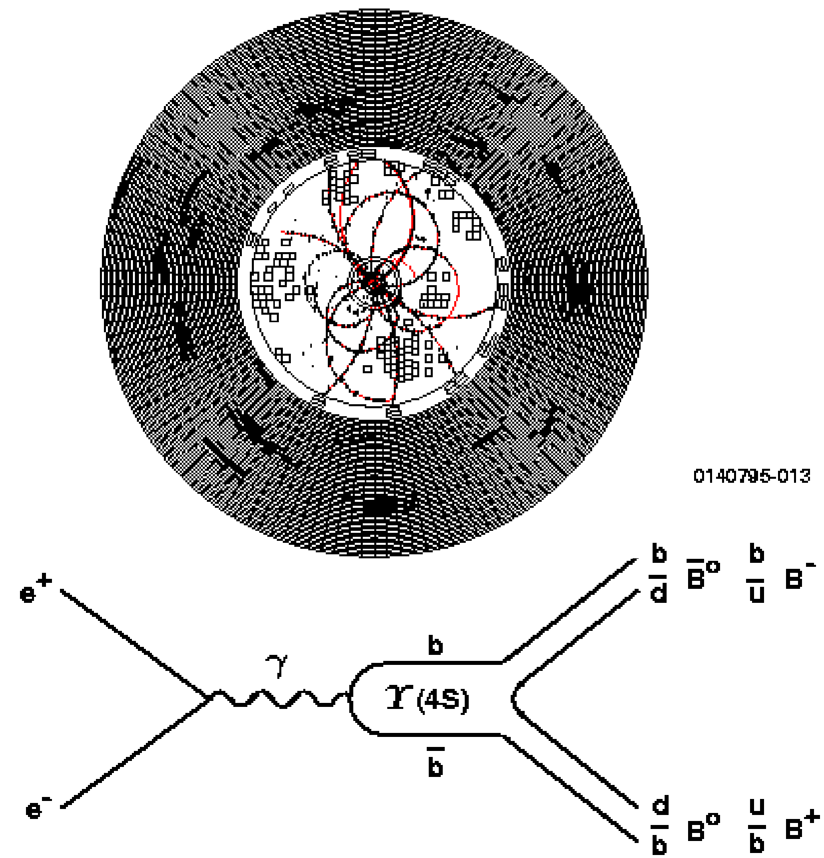




Two CLEO events:

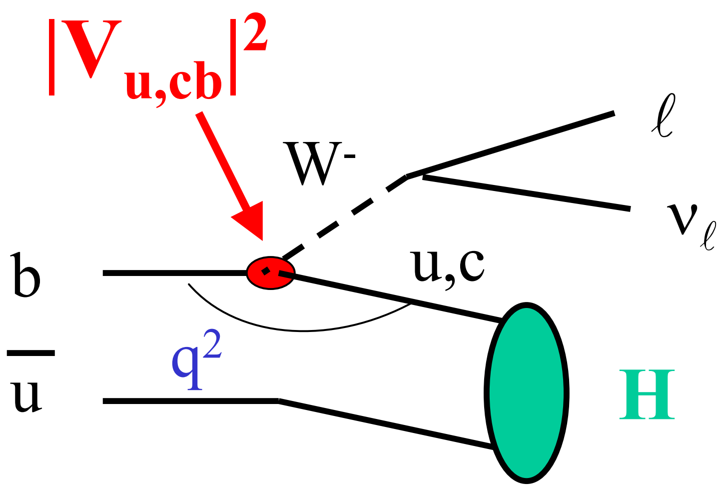
$e^+e^- \to \gamma^* \to q\bar{q}$ $\qquad$ $e^+e^- \to \gamma^* \to \Upsilon(4S) \to B\bar{B}$



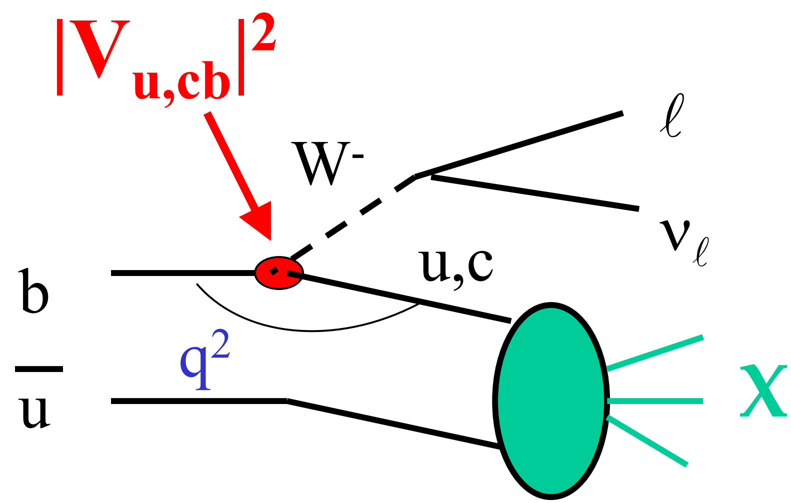


A direct route to $|V_{cb}|$ and $|V_{ub}|$: Semileptonic $b \to u,c$ transitions

exclusive



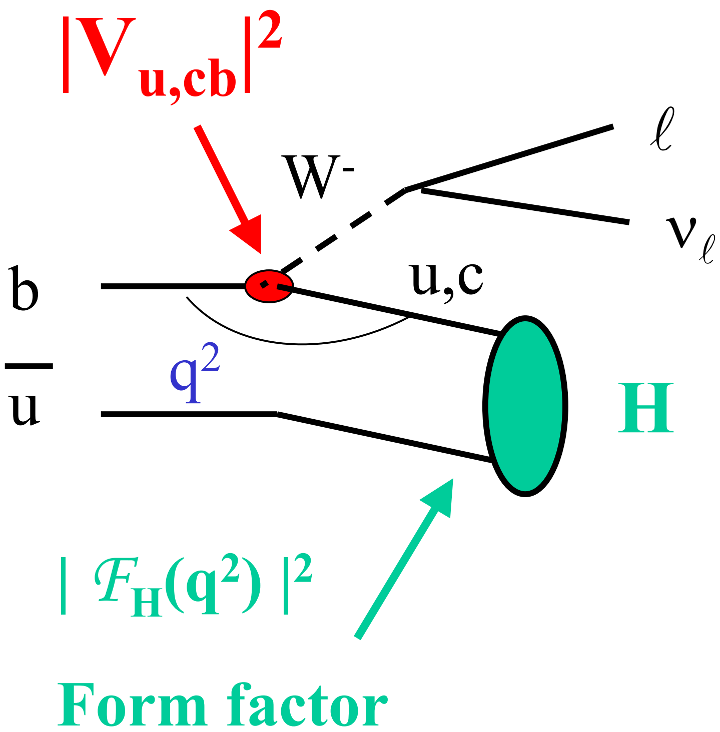
inclusive



- Why use several techniques? Independent systematics, cross check, different theoretical problems!

exclusive

A direct route to V_{cb} and V_{ub}: semileptonic $b \to c,u$ transitions



Rate for a final state with a particular hadron:

$$\frac{d\Gamma_{sl}}{dq^2}\left(B \to H_{u,c}\, l\nu\right) \propto \begin{pmatrix}\textbf{kinematic}\\ \textbf{factor}\end{pmatrix} \times \boxed{\left|V_{u,cb}\right|^2} \times F_H^2(q^2)$$

Form factor can be measured or taken from theory

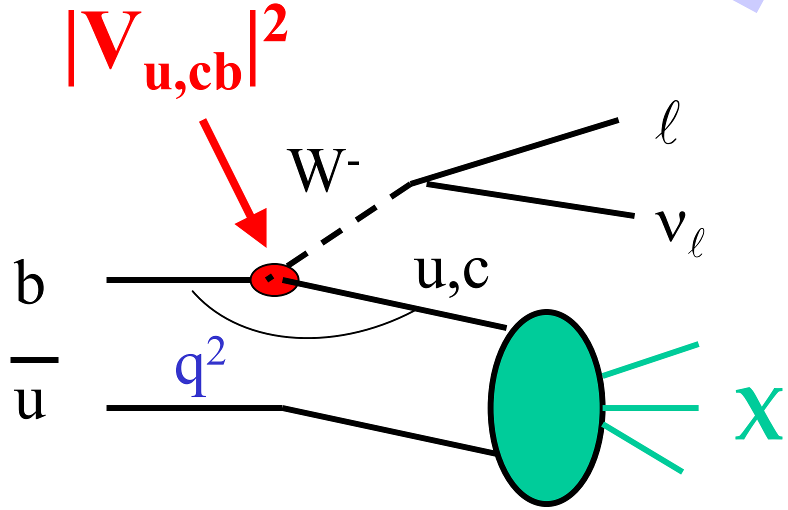
A direct route to V_{cb} and V_{ub}: semileptonic b→c,u transitions

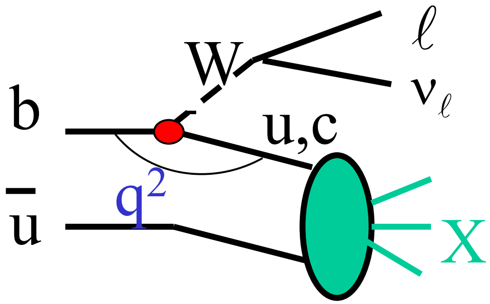
inclusive

Theory can predict

- **total inclusive rate**
  - On average, integrate over enough exclusive bound states and phase space ⇒ inclusive hadronic result will match quark level calculations

Framework: Heavy **Q**uark **E**ffective **T**heory to calculate observables, example see next slide





$\Gamma_{sl}(B\to X_c l\nu) \leftrightarrow V_{cb}$ using OPE/HQET

Expansion in powers of α_S and Λ_{QCD}/m_B:

$1/M_B$ $(1/M_B)^2$ $(1/M_B)^3$

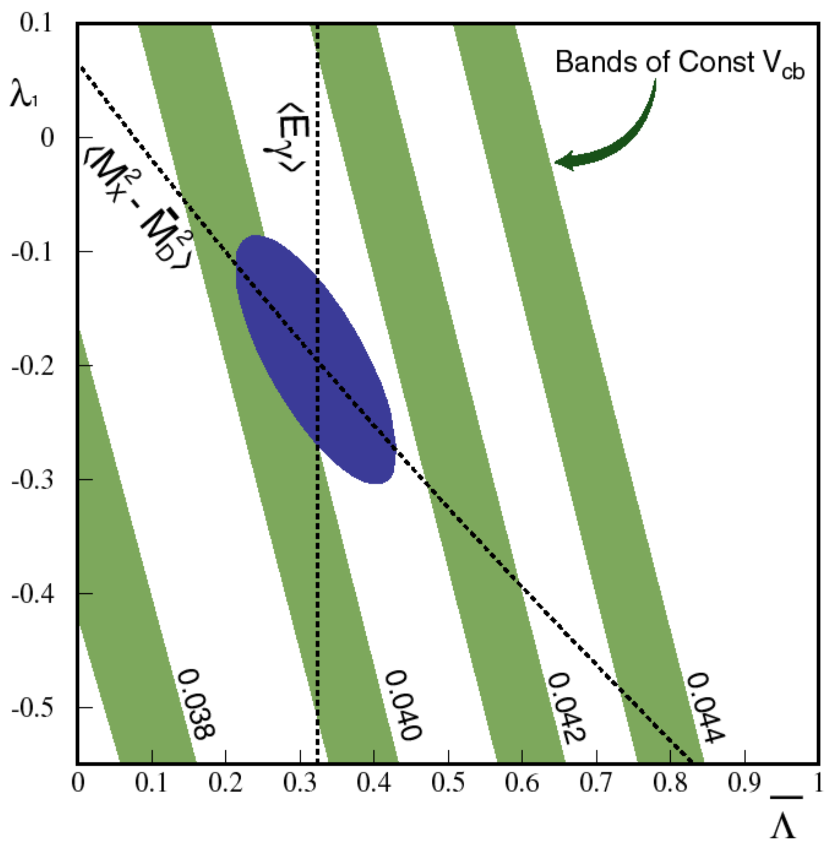
$$\Gamma_{sl}(B\to X_c l\nu) = \frac{G_F^2 |V_{cb}|^2 M_B^5}{192\pi^3} 0.3689 \Bigg[1 - 1.54\frac{\alpha_s}{\pi} - 1.43\beta_0\left(\frac{\alpha_s}{\pi}\right)^2 - 1.648\frac{\bar{\Lambda}}{M_B}\left(1 - 0.87\frac{\alpha_s}{\pi}\right) - 0.946\left(\frac{\bar{\Lambda}}{M_B}\right)^2 - 3.185\frac{\lambda_1}{M_B^2} + 0.02\frac{\lambda_2}{M_B^2} - 0.298\left(\frac{\bar{\Lambda}}{M_B}\right)^3 - 3.28\frac{\lambda_1\bar{\Lambda}}{M_B^3} + 10.47\frac{\lambda_2\bar{\Lambda}}{M_B^3} - 6.153\frac{\rho_1}{M_B^3} + 7.482\frac{\rho_2}{M_B^3} - 7.4\frac{\tau_1}{M_B^3} + 1.491\frac{\tau_2}{M_B^3} - 10.41\frac{\tau_3}{M_B^3} - 7.482\frac{\tau_4}{M_B^3} + \mathcal{O}\left(\frac{1}{M_B^4}\right)\Bigg]$$

$\mathcal{O}(M_B^{-1})$: $\bar{\Lambda}$, **energy of light quark and gluon dof inside B (m_B-m_b)**

$\mathcal{O}(M_B^{-2})$: λ_1, **average kinetic energy of b**, and λ_2 (hyperfine splitting, from $\Delta m(B,B^*)$)

$\mathcal{O}(M_B^{-3})$: $\rho_{1,2}$, $\tau_{1..4}$ (estimated)

$(\lambda_1,\overline{\Lambda})$ plane and V_{cb}



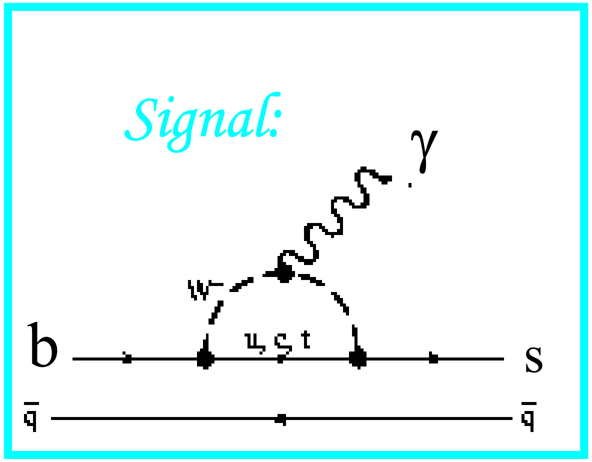
So how do we get to λ_1, $\overline{\Lambda}$?

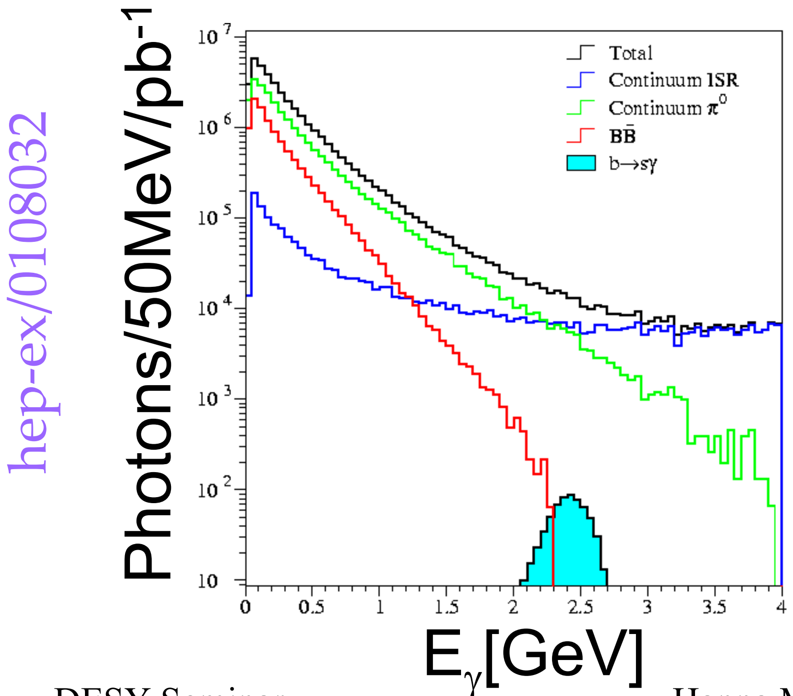
3 approaches.

A helper process with its own virtue: $b \to s\gamma$

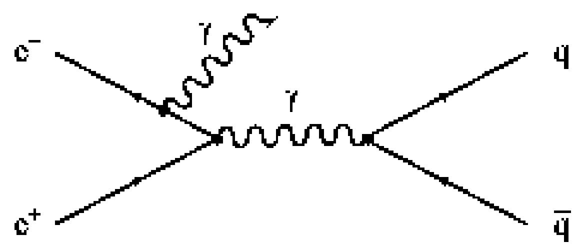
DETOUR, inclusive $b \to c$ afterwards

- **FCNC process, vanishes at tree level**
- **Heavy to light transition**





- Can easily be confused e.g. with $e^+e^- \to e^+e^- \gamma \to q\bar{q}\gamma$

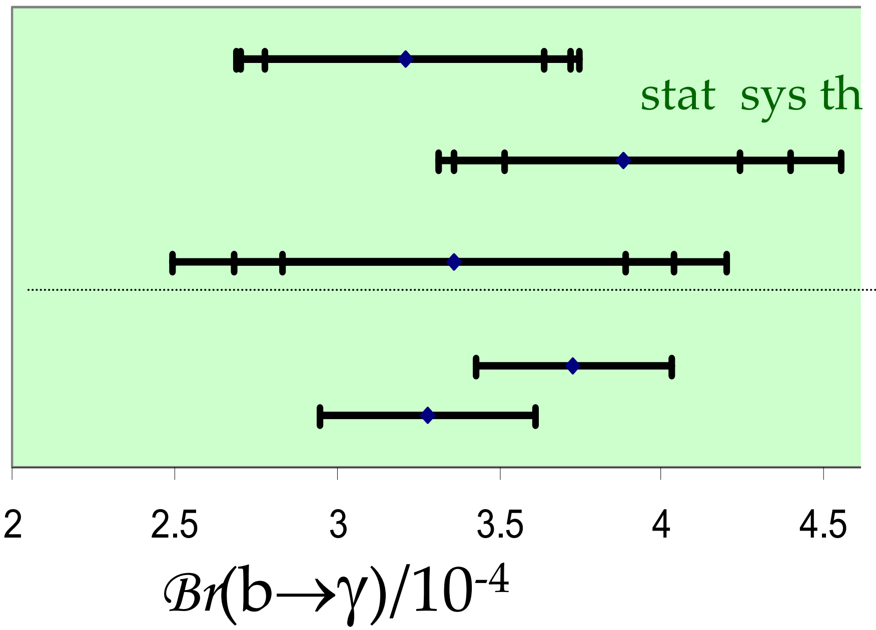


- Use event shape cuts and neural net

Goals: rate, E_γ spectrum

Rate: New physics in b→sγ?

- **sensitive to non-SM contributions (considerable interest from theorists…)**



CLEO 2001

$9.1 fb^{-1}$ ON, **4.4**fb^{-1} OFF

BaBar ICHEP 02 (B→$X_s\gamma$)

$54.6\ fb^{-1}$ ON, 6.4 OFF

Belle 2001 (B→$X_s\gamma$)

$5.8 fb^{-1}$ ON, $0.6 fb^{-1}$ OFF

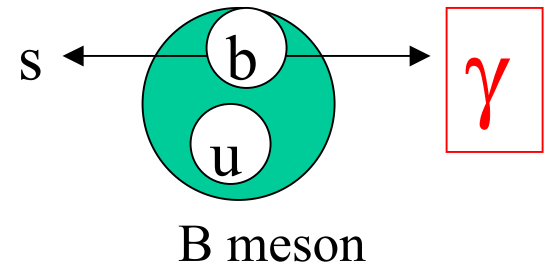
SM (Chetyrkin et al. 1997)

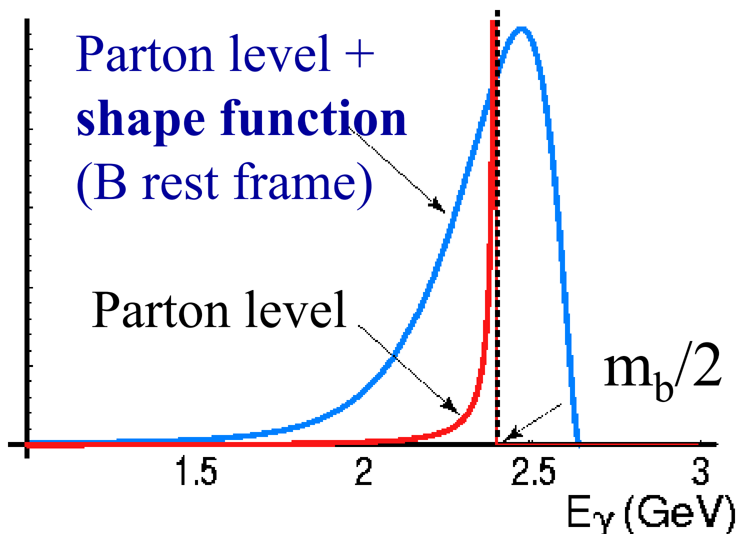
SM (Gambino et al., 2001)

◆ **Consistency with SM (also for A_{CP})**

E_γ spectrum in $b \to s\gamma$: From partons to hadrons

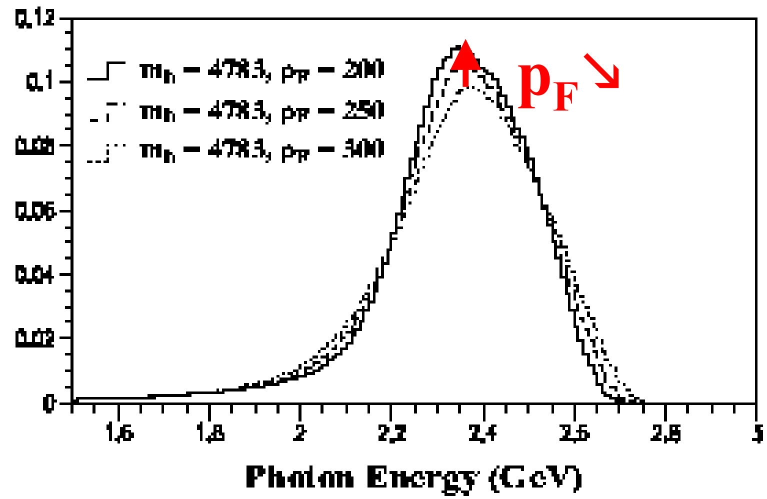
- Doppler broadening due to Fermi motion of the b within the B
- Leaves total rate unaffected
- Options include the Spectator Model (need m_b and p_F) and Shape Functions (convolute with parton level calculation, eg. $b \to sg\gamma$ – **ANY heavy to light transition!!**)
- Cannot be calculated from first principles, need experimental input

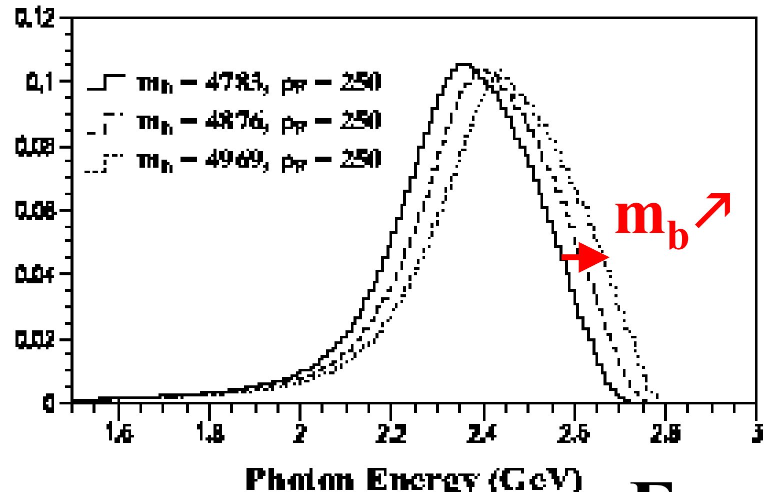




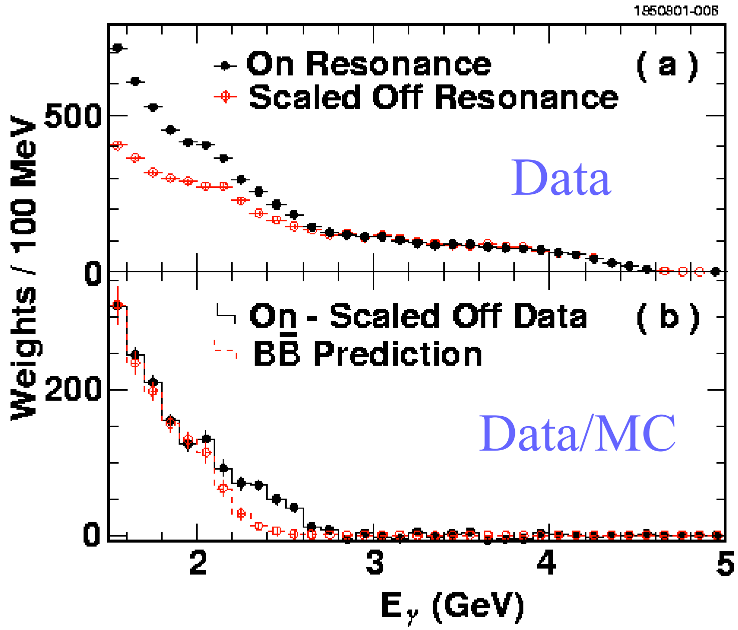
Using the b→sγ photon energy spectrum

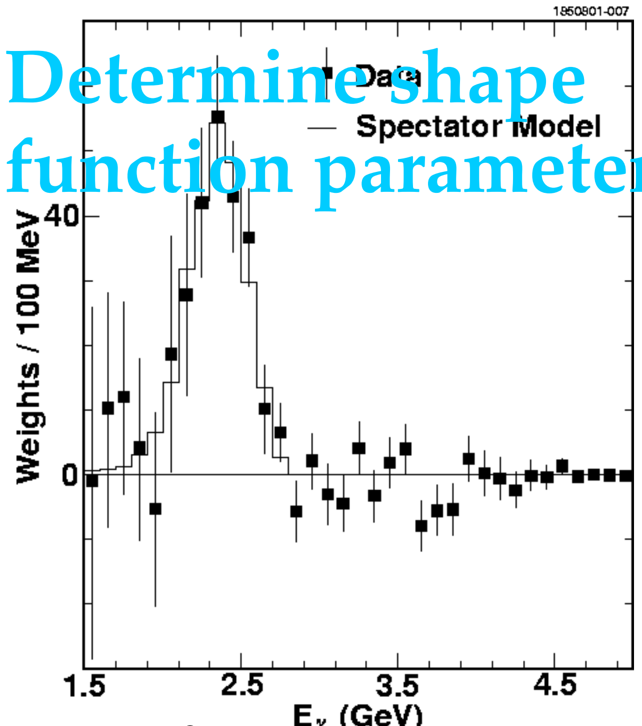
- **monoenergetic photon**
  mean controlled by m_b, smeared by
  - gluon bremsstrahlung → pQCD
  - Doppler broadening due to Fermi motio (p_F)
  - Boost and detector resolution → experimental problem
- **Moments of E_γ** related to HQET parameters:
  - Mean → $\bar{\Lambda}$ **(m_b or energy of light q's and g's)**,
  - RMS → $\lambda_1(\bar{\Lambda})$ **(kinetic energy of b)**





$b \to s\gamma$: Photon Energy Spectrum Results





Determine shape function parameters!

$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011\,\mathrm{GeV}$

$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0226 \pm 0.0066 \pm 0.0020\ \mathrm{GeV}^2$

HQET: $\langle E_\gamma \rangle$, $\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 \to \bar{\Lambda}$, λ_1

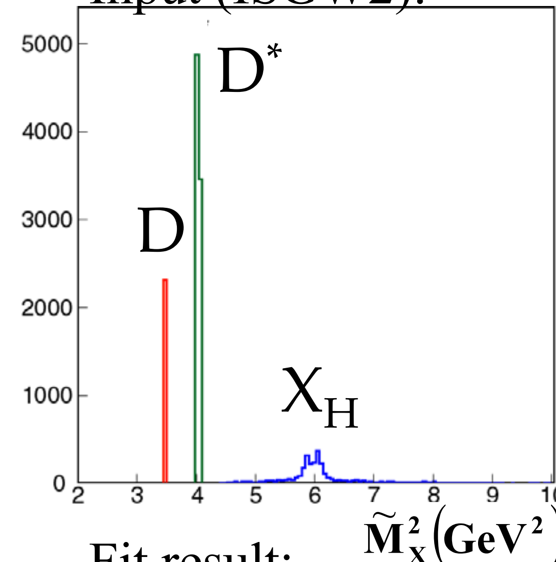
Hadronic Mass Moments in $B \to X_c l\nu$ Decays

hep-ex/0108033

A second way of getting $\bar{\Lambda}, \lambda_1$

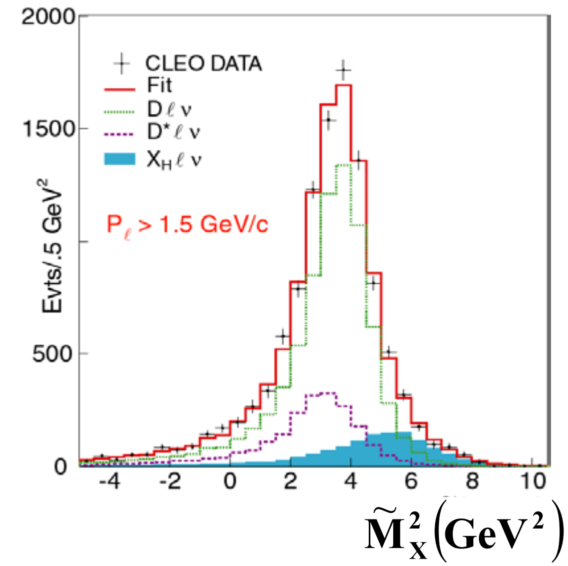
- Select $b \to cl\nu$ events, $p_l > 1.5\text{GeV}$, subtract continuum & $ul\nu$ backgrounds
- Fit $\tilde{M}_X^2 = M_B^2 + M_{l\nu}^2 - 2E_B E_{l\nu}$ distribution with
  - $B \to Dl\nu, D^*l\nu$
  - Higher resonances
  - Non-resonant production

Input (ISGW2):



D. Cronin-Hennessy

Fit result:



$B \to X_C l\nu$: Hadronic mass moments

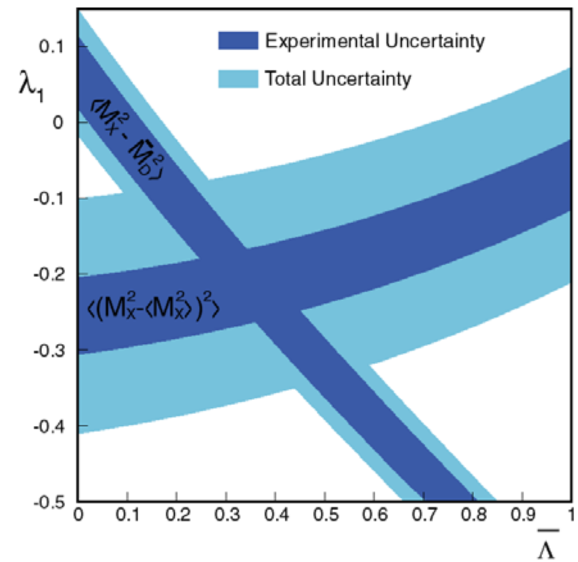
- Theory provides

Spin-averaged D meson mass

$$\frac{\left\langle M_X^2 - \overline{M_D^2} \right\rangle}{M_B^2} = f\left(\lambda_1, \overline{\Lambda}; \rho_{1,2}, \tau_{1..4}\right)$$

$$\frac{\left\langle \left(M_X^2 - \left\langle M_X^2 \right\rangle\right)^2 \right\rangle}{M_B^4} = g\left(\lambda_1, \overline{\Lambda}; \rho_{1,2}, \tau_{1..4}\right)$$

❖ Convergence concerns for second moment for both $b \to s\gamma$ (E_γ) and $B \to X_C l\nu$ (hadronic mass moments)



Combining $b \to s\gamma$ and $B \to X_C l\nu$ gives:

$$O\left(M_B^{-3}, \beta_0 \alpha_S^2\right), \overline{MS}:$$

$$\overline{\Lambda} = 0.35 \pm 0.07 \pm 0.10\,\text{GeV}$$

$$\lambda_1 = -0.236 \pm 0.071 \pm 0.078\,\text{GeV}^2$$

$\bar{B} \to X_c l \bar{\nu}$ lepton moments

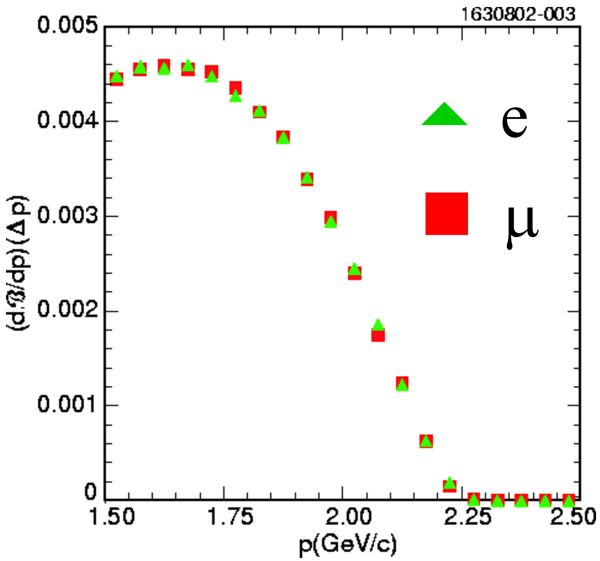
A third way of getting $\bar{\Lambda}$, λ_1

- Measure lepton spectrum, p>1.5GeV, l=e,μ
- Subtract background (cont, fake leptons, real background leptons), correct E_l spectrum
- Moments:

$$R_0[R_1] = \frac{\int_{1.7[1.5]} [E_l](d\Gamma_{sl}/dE_l)dE_l}{\int_{1.5} (d\Gamma_{sl}/dE_l)dE_l}$$

$$= (\text{theory :}) f(\bar{\Lambda}, \lambda_1)$$

Corrected p_l spectrum:



λ_1= -0.25±0.02±0.05±**0.14**

$\bar{\Lambda}$ = 0.39±0.03±0.06±**0.12**

stat syst **theo**

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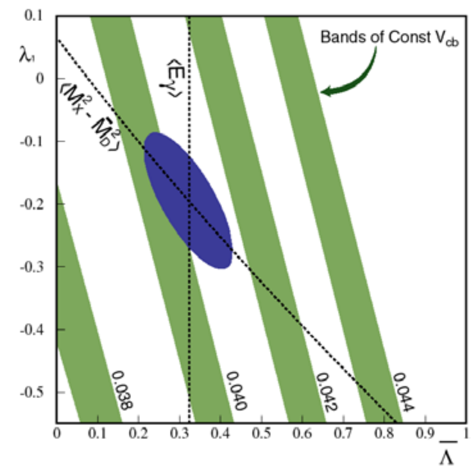
From the HQET parameters to V_{cb}



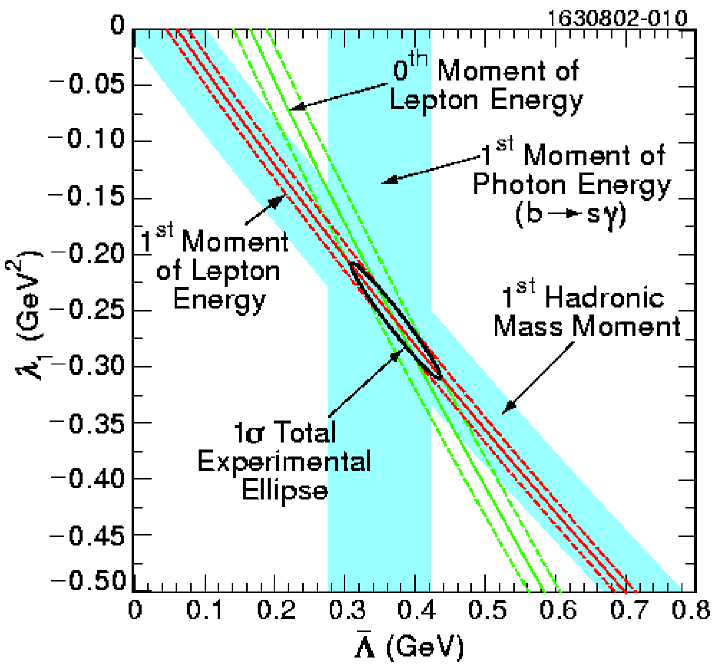
- 3 results on HQE parameters ($\bar{\Lambda}$,λ_1):

($\bar{\Lambda}$ -- (m_B-m_b) , λ_1 -- average kinetic energy of b in B)

- **b→sγ**: <E_γ>+theory ⇒ $\bar{\Lambda}$
- **B→X$_c$lν**: <M_X^2-$\bar{M}_D^2$>+theory ⇒ $\lambda_1(\Lambda)$
- **B→X$_c$lν**: lepton moments R_0 and R_1+ theory ⇒ 2x$\lambda_1(\bar{\Lambda})$
  - At O(M_B^{-3}): $\bar{\Lambda}$, λ_1, λ_2, $\rho_{1,2}$, $\mathcal{T}_{1..4}$ (only estimates, must rely on rapid convergence)
  - Could, in principle, determine all parameters conducting multiple experiments

- Consistent results?
- Is parton hadron duality a good assumption, and how to quantify resulting uncertainties?

$|V_{cb}|$ inclusive comparison



- Important test of HQE
- 3% precision on V_{cb}, good agreement
- Theoretical error needs to improve
- Note the impact of Γ_{sl}

Hadronic mass in $B \to X_c l\nu + b \to s\gamma$:

$$|V_{cb}| = (\, 40.4 \pm 0.9(\Gamma_{sl}^{CLEO}) \pm 0.5(\lambda_1,\Lambda) \pm 0.8(th)\,) \times 10^{-3}$$

E_l: $|V_{cb}| = (\, 40.8 \pm 0.5(\Gamma_{sl}^{WW}) \pm 0.4(\lambda_1,\Lambda) \pm 0.9(th)\,) \times 10^{-3}$

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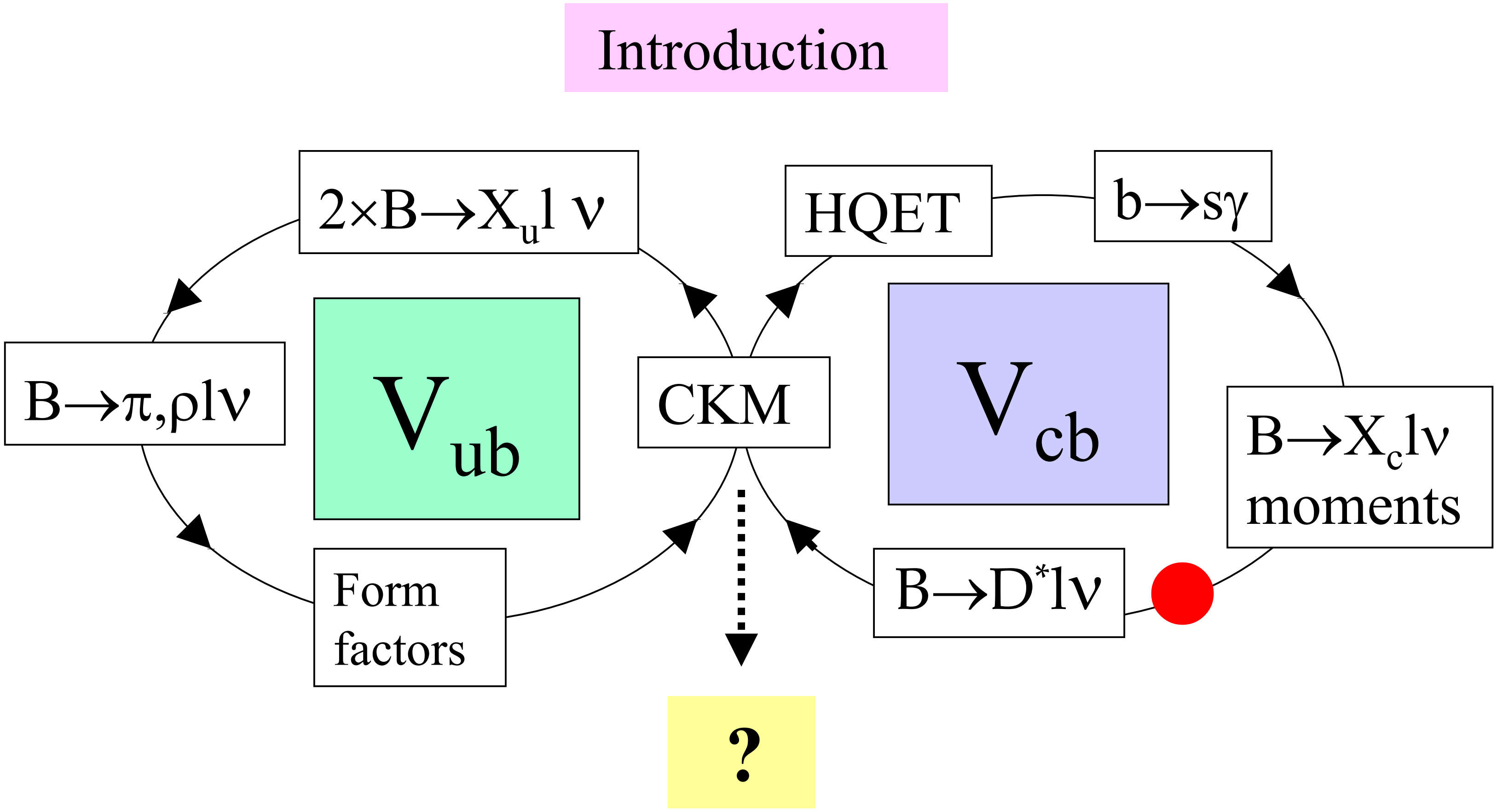


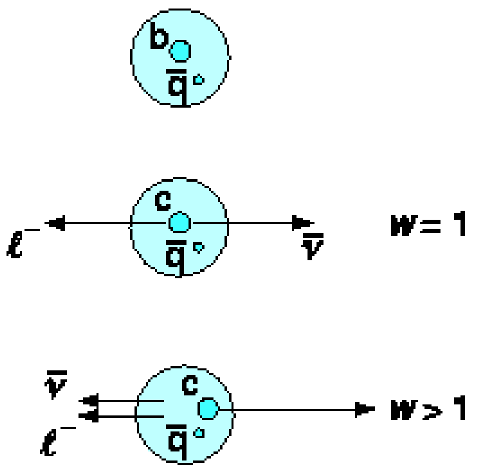
Introduction
$2\times B\to X_u l\,\nu$
HQET
$b\to s\gamma$
$B\to\pi,\rho l\nu$
V_{ub}
CKM
V_{cb}
$B\to X_c l\nu$ moments
Form factors
$B\to D^* l\nu$
?

V_{cb} **exclusive**: $B \to D^{(*)} l\nu$

- From semileptonic decay rate to V_{cb}:

$$d\Gamma^{B\to D(*)l\nu}/dw = G_F^2/48\pi^3 K(w)\, |\mathbf{V_{cb}}|^{\mathbf{2}} \mathcal{F}_{D(*)}{}^2(w)$$

  - **$w=v_B \cdot v_D$**, Lorentz boost of D* in B rest frame; also $w=(m_B{}^2+m_{D*}{}^2- \mathbf{q^2})/(2m_B m_{D*})$
  - **K(w):** known kinematical factor
  - Theory constrains shape of $\mathcal{F}$ and normalization $\mathcal{F}(1)$ (≈1 in HQET) $w=1 \to$ D is at rest w.r.t. B.



$$\mathcal{F}(w)=\left\{\begin{array}{l}\text{fct of various form factors,}\\ \text{related, parametrized (slope } \rho)\end{array}\right\} = f(\mathcal{F}(1),\rho^2;\mathbf{w})$$

➢ Can measure shape and $\mathcal{F}(1)^2|V_{cb}|^2$.

V_{cb} exclusive: $B^0 \to \mathbf{D^{*+}} l^- \nu$, $B^- \to \mathbf{D^{*0}} l^- \nu$ signal yield

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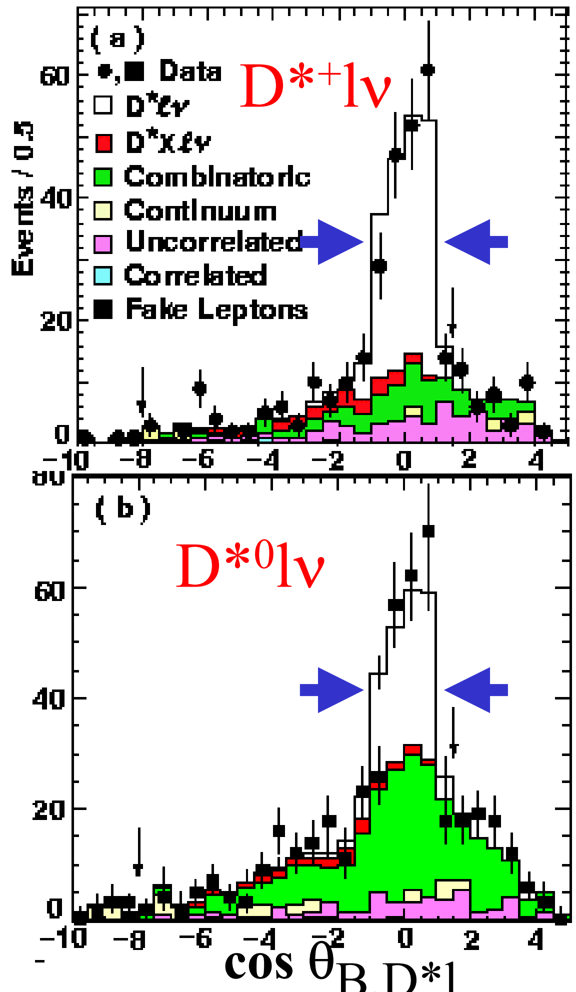


(1.10<w<1.15)

- Reconstruct $D^* \to \pi_s D^0 \to \pi_s(K^- \pi^+)$, add e or μ
- Use **$\cos\theta_{B,D^*l}$**, assume there is exactly one ν, to compute w and to suppress background:
  - **–1..1 for signal events**
  - combinatorically rec'd D^*'s constitute largest background
- **Fit** for composition and obtain true D*lν yield for each w bin

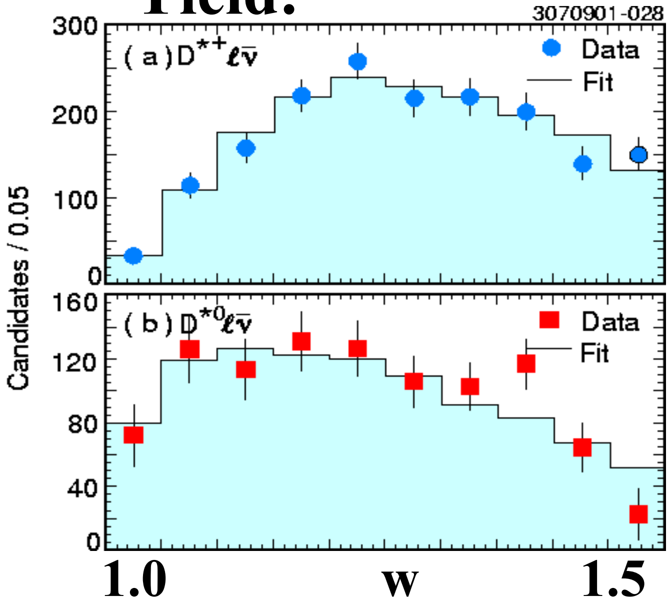
V_{cb} fit

$(d\Gamma^{B\to D^{*}l\nu}/dw = \ldots |V_{cb}|^2 \mathcal{F}(1)^2 f(\rho;w)^2)$

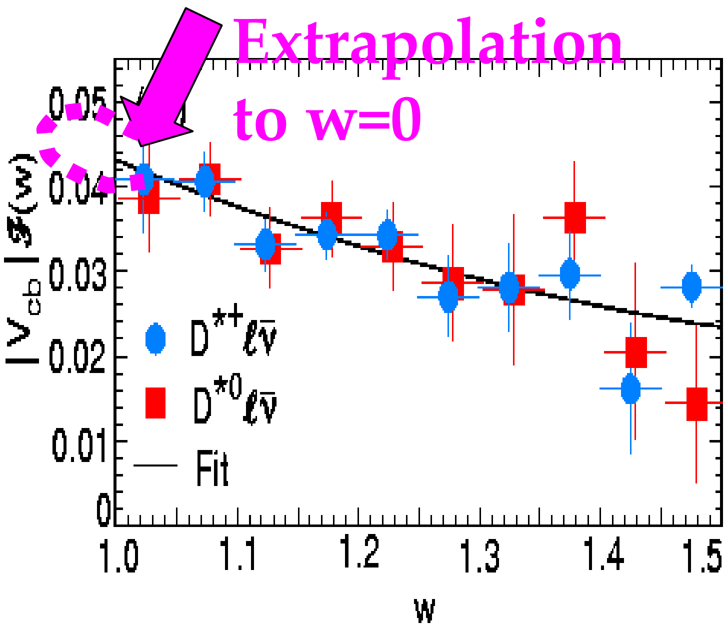
- $\mathcal{F}(1) = 0.913^{+0.030}_{-0.035}$ (lattice)

•$\rho^2 = 1.61 \pm 0.09 \pm 0.21$

Yield:



Extrapolation to w=0



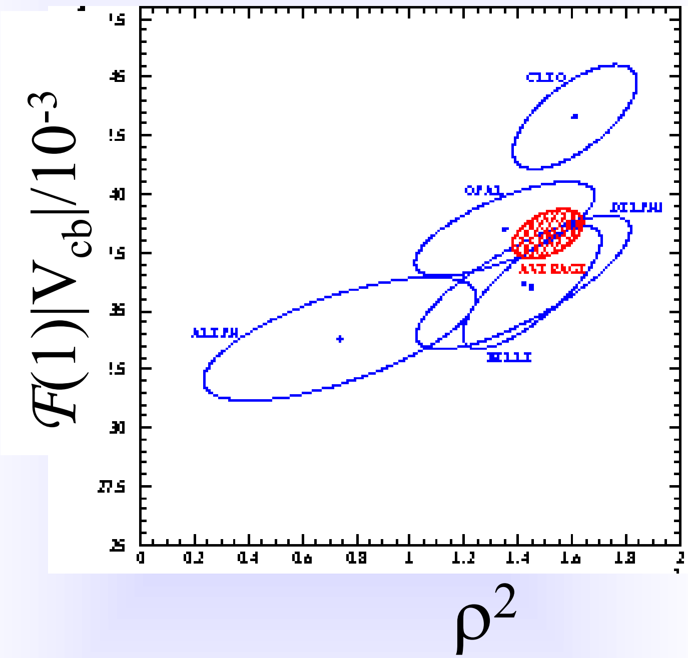
$Br(\bar{B}^0 \to D^{*+} l^- \bar{\nu}) = (6.09 \pm 0.19 \pm 0.40)\%$

$Br(B^- \to D^{*0} l^- \bar{\nu}) = (6.50 \pm 0.20 \pm 0.43)\%$

$|V_{cb}| = (46.9 \pm 1.4 \pm 2.0 \pm 1.8) \times 10^{-3}$

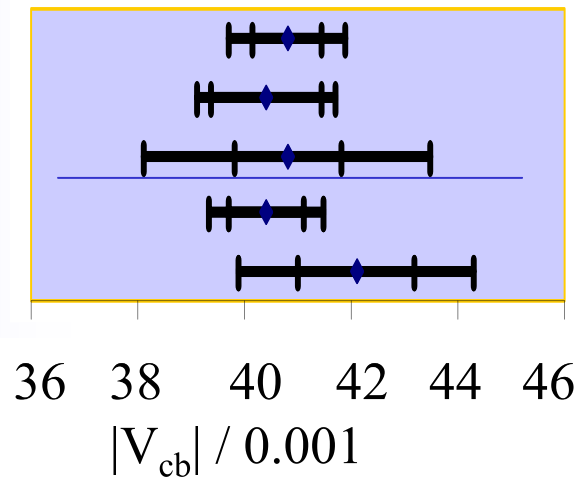
stat syst theo

$B \to D^{(*)} l \nu$ (hep-ph/0205163)



V_{cb} worldwide

Inclusive determination and inclusive/exclusive averages:



CLEO Hadr mass
CLEO ℓ energy
Belle Γ_{sl}
LEP + Υ(4S) incl
$B \to D^{(*)} l \nu$ world average

$\delta V_{cb} / V_{cb}$=3…5%

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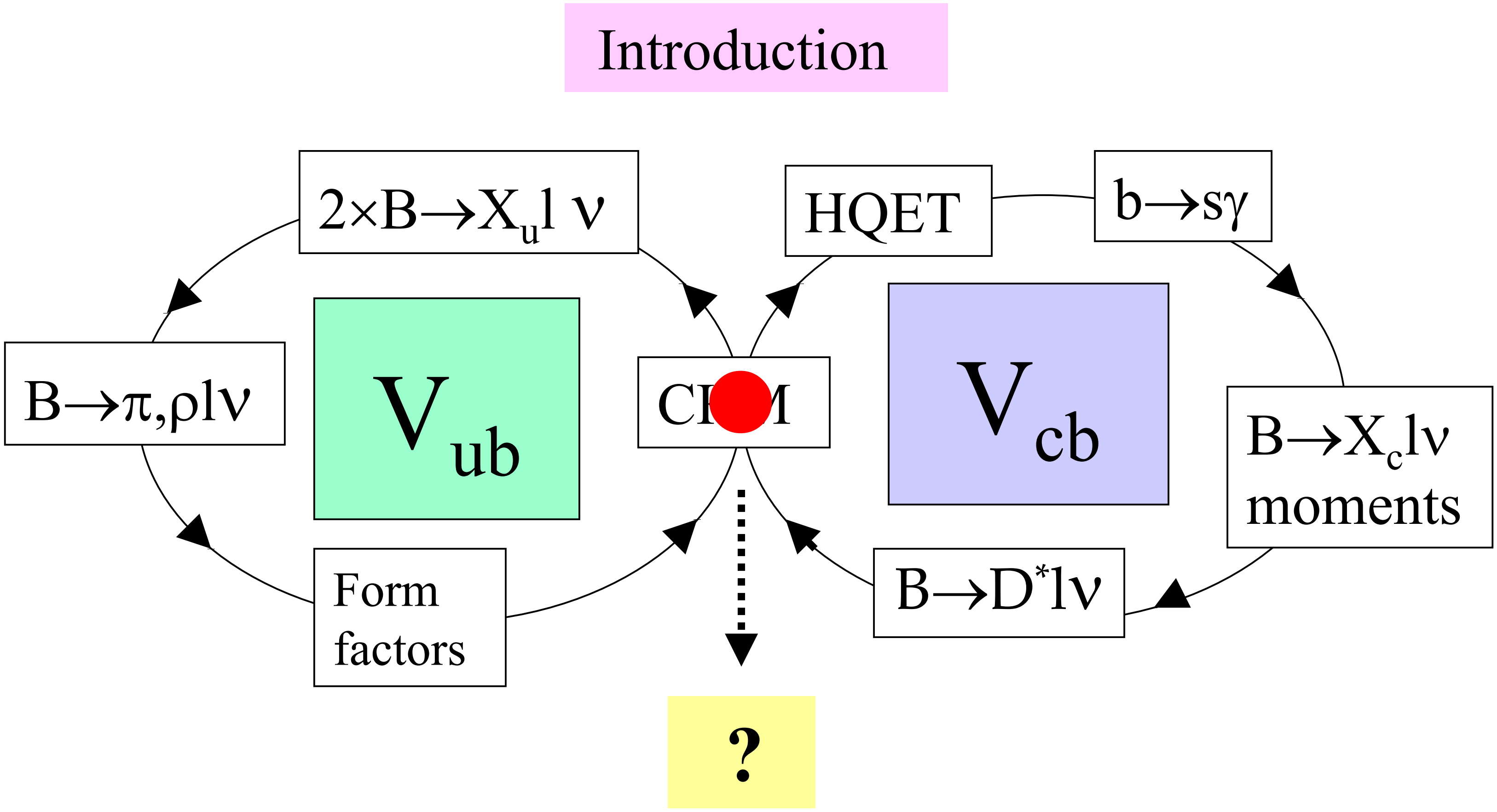
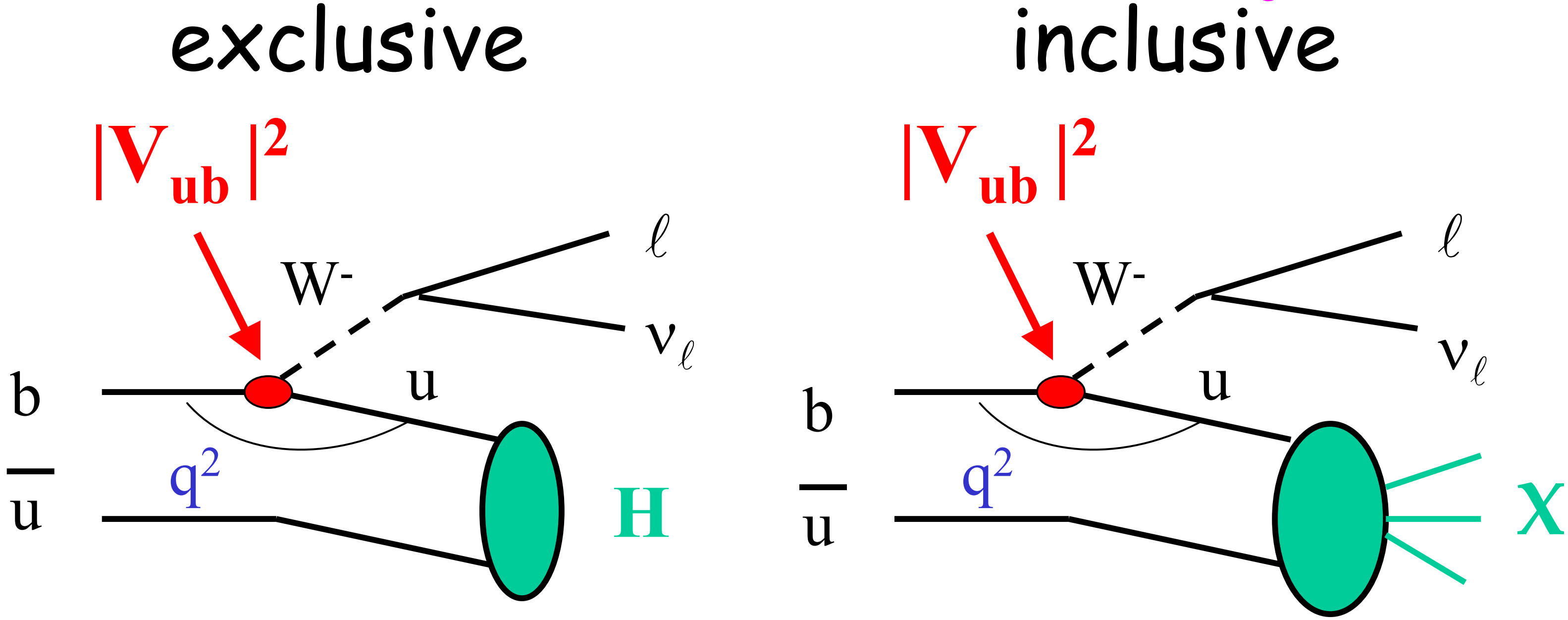

Introduction
2×B→X$_u$l ν
HQET
b→sγ
B→π,ρlν
V$_{ub}$
CKM
V$_{cb}$
B→X$_c$lν moments
Form factors
B→D*lν
?

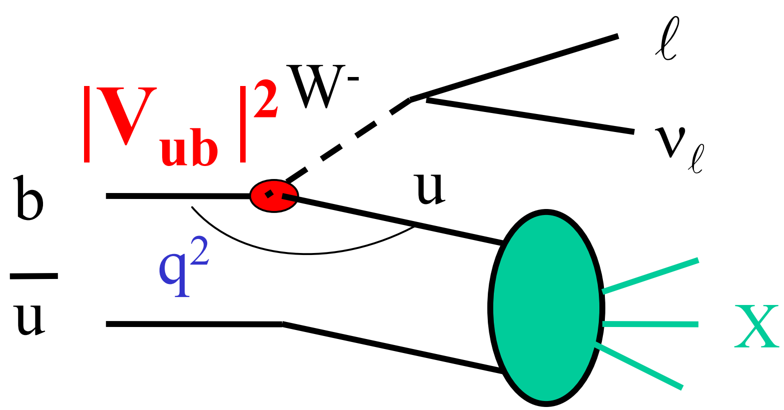
A direct route to V_{cb} and V_{ub}: Semileptonic $b \to u,c$ transitions

YOU HAVE SEEN THIS SLIDE BEFORE!!!



- Why use several techniques? Independent systematics, cross check, different theoretical problems!

From V_{cb} to V_{ub}



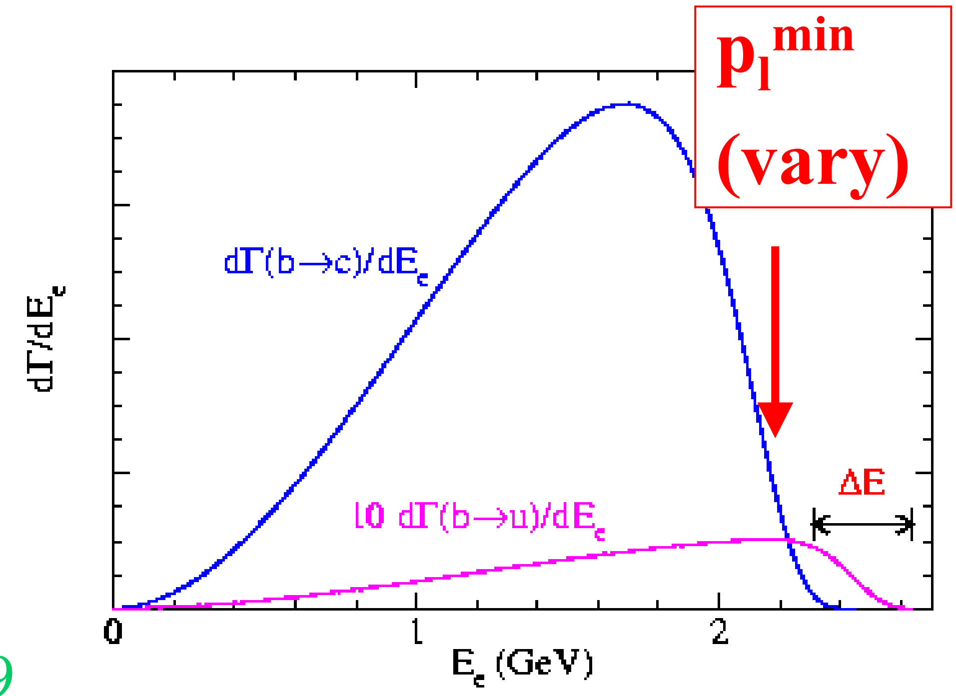
- $(V_{ub}/V_{cb})^2 = 0.01$
- **Exclusive** –
  – Formation of hadrons is similar; form factor is one of the big uncertainties

- **Inclusive –**
  - ❖ Differs theoretically as u is not heavy (heavy quark symmetries not valid)
  - ❖ Regions in phase space where $u l \nu$ is enhanced w.r.t. $c l \nu$ usually are regions with either theoretical challenges (lepton endpoint) or experimentally not clean (high q^2, low M_X)

1^{st} ulν preferred region → $|V_{ub}|$: the 'endpoint' lepton spectrum

$$|V_{ub}| = (3.07 \pm 0.12) \times 10^{-3} \times \left[\frac{\boxed{\mathrm{Br}(B \to X_u \ell \nu)}}{0.001} \frac{1.6\mathrm{ps}}{\tau_B} \right]^{1/2}$$

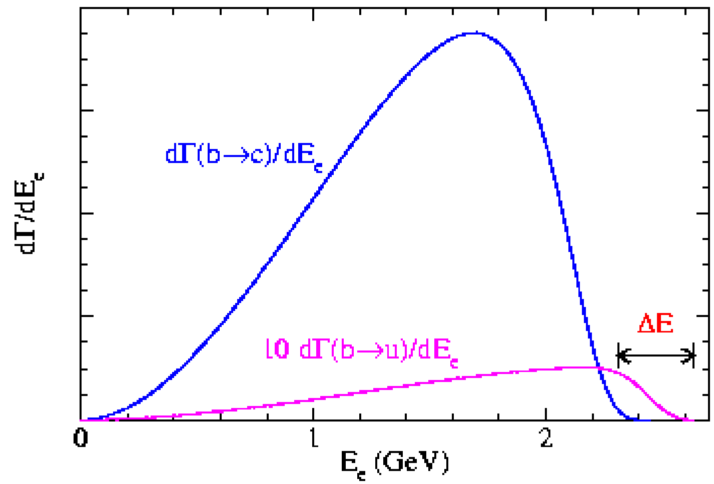
- Measure lepton energy spectrum for $E_l = p_l^{min} \ldots 2.6\mathrm{GeV/c}$
- Trade experimental against theoretical uncertainties by varying the lower limit (extrap^n ↔ clν bkgd)

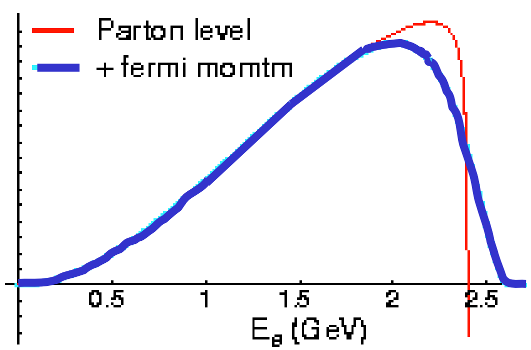


hep-ex/0202019

$|V_{ub}|$ inclusive measurement I: the lepton 'endpoint' spectrum ($|V_{ub}|=\ldots(\boxed{B(b \to ul\nu)}/\tau_B)^{1/2}$)

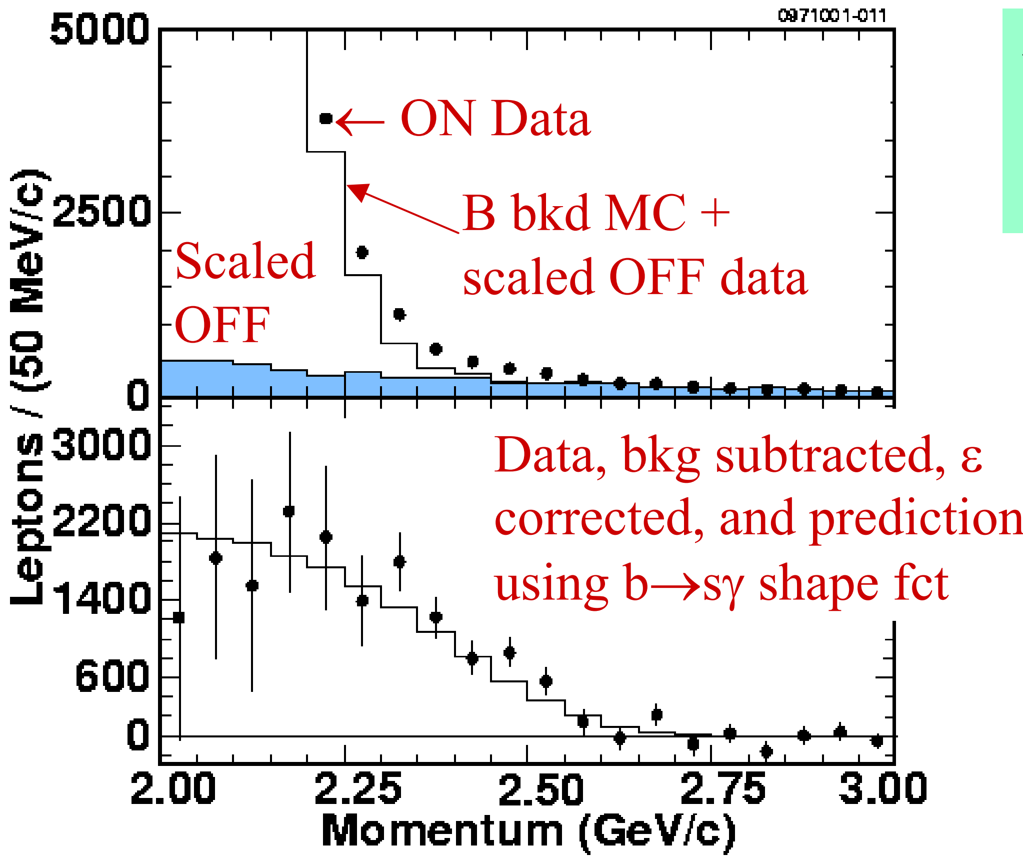
- **Measure** lepton spectrum for E_l=2.x…2.6GeV/c, **extrapolate** to full range
- Previously had to resort to models for extrapolation





Remember $b \to s\gamma$, another heavy to light transition: **shape function**!

➢ calculate parton level, use $b \to s\gamma$ shape function (check with models)



V_{ub} incl from lepton endpoint analysis

Background suppression:

- Cont: neural net for event shape information
- B →clν: account for in fit using MC

Check analysis with different p_l^{min} cuts

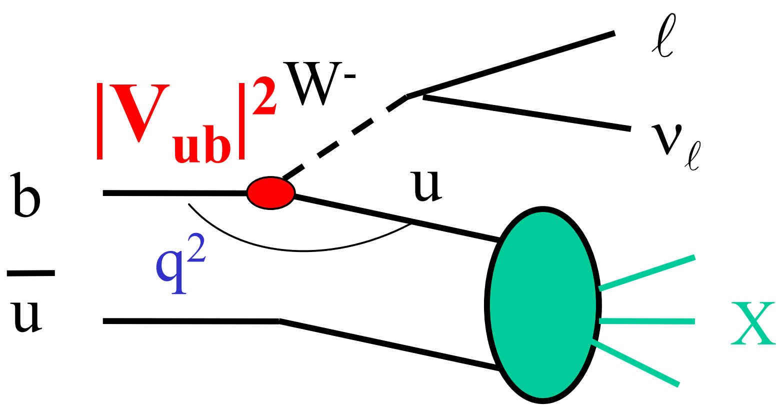
$|V_{ub}|$=4.08±0.63 (2.2…2.6GeV/c)

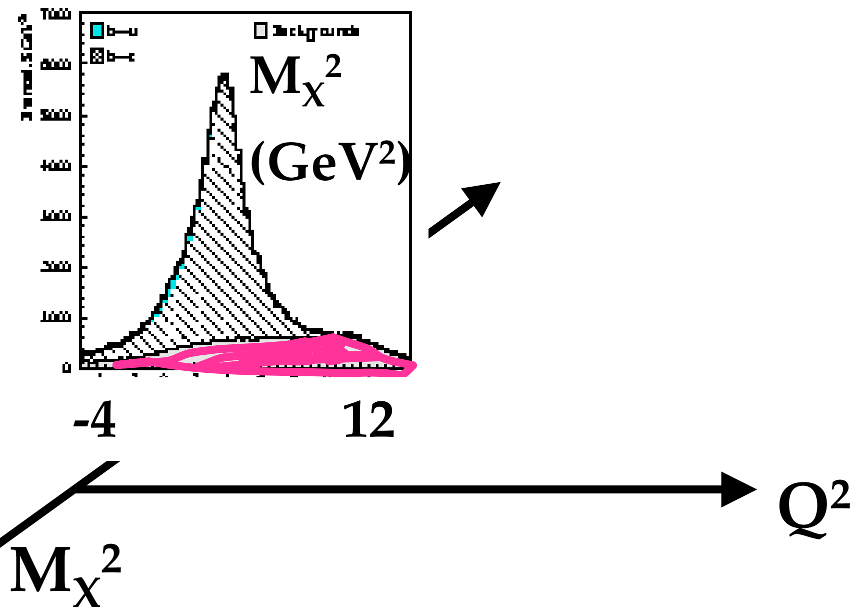
(dominant error from extrapolating to the full p_l range)

2^{nd} $u l\nu$ preferred region: high q^2 & low M_X^2

$B \to X_u l\nu$ (MC)	ISGW2 …. non-res	
$B \to X_c l\nu$ (MC)	$B \to D, D^{**} l\nu, B \to D^{*} l\nu$, $B \to X_c$ non-resonant	
background	qq, fake and sec leptons	

❖ Keep **all** semileptonic B events, again determine BR($b \to u l\nu$)





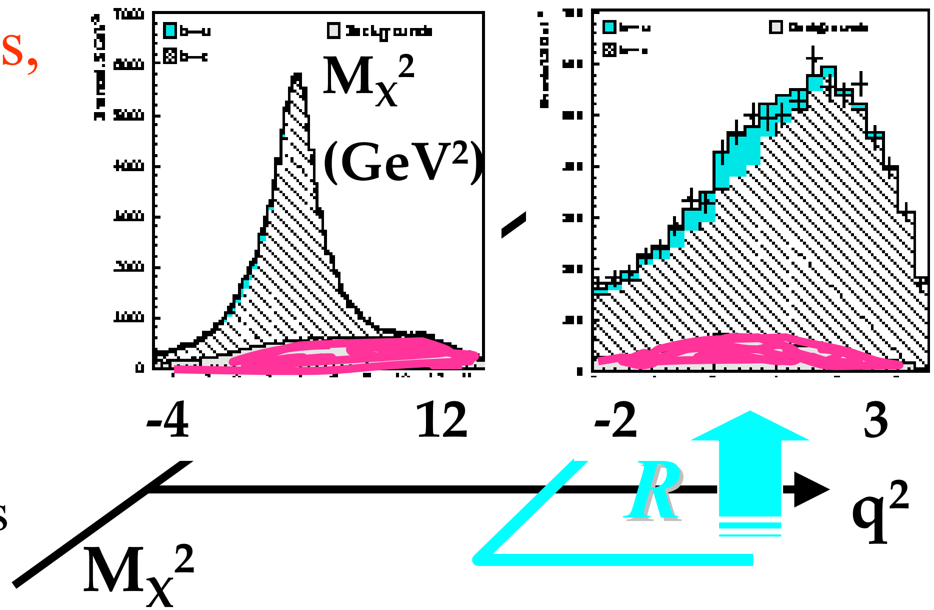
hep-ex/0207064 (ICHEP 02 prelim)

❖Use $cl\nu$ to determine moments$\to |V_{cb}|$ (in progress)

2^{nd} $u l \nu$ preferred region: high q^2 & low M_X^2

$B \to X_u l \nu$ (MC)	ISGW2 …. non-res	
$B \to X_c l \nu$ (MC)	$B \to D, D^{**} l \nu, B \to D^* l \nu$, $B \to X_c$ non-resonant	
background	cont, fake and sec leptons	

- Keep **all** semileptonic B events, again determine $BR(b \to u, c l \nu)$
- V_{ub}:
  - $u l \nu$ in $\boldsymbol{R}$=(high q^2, low M_X^2)!
  - $\boldsymbol{R}$ theoretically preferred
  - scale down by fraction of events in $\boldsymbol{R}$, do this with several models to evaluate systematic error, use HQET in $\boldsymbol{R}$

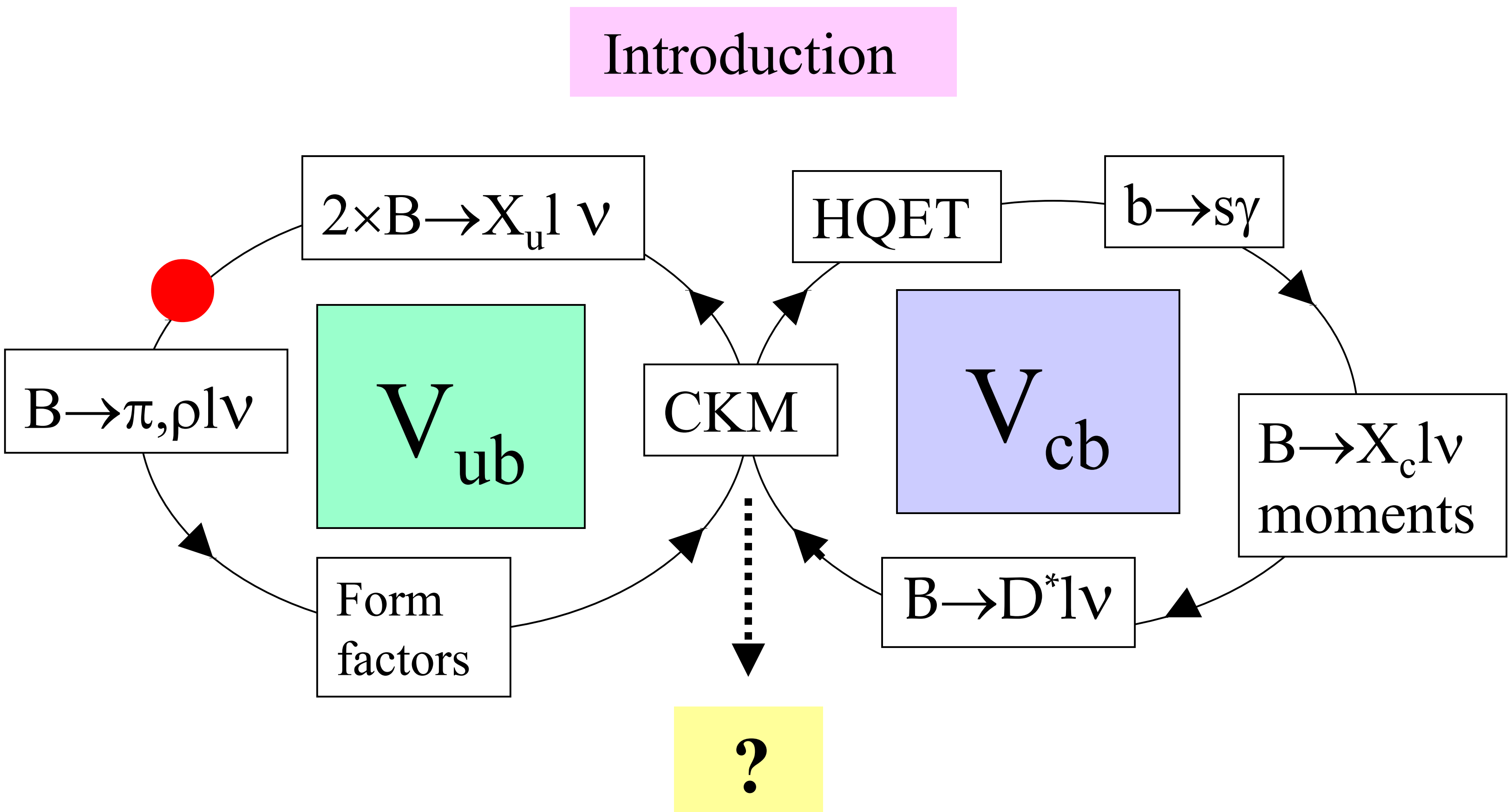


hep-ex/0207064 (ICHEP 02 prelim)

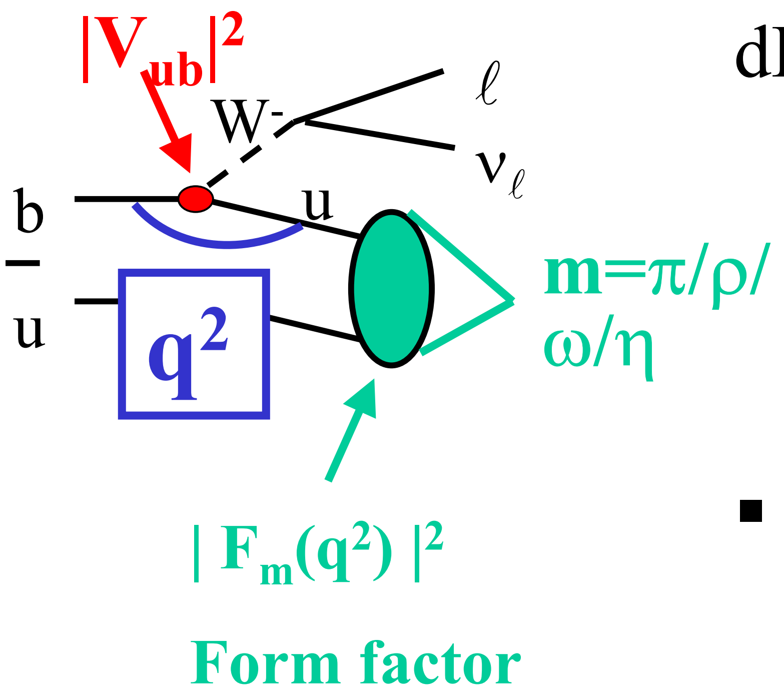
$$|V_{ub}| = (4.05 \pm 0.18 \pm 0.58 \pm 0.25 \pm 0.21 \pm 0.56) \times 10^{-3}$$

stat syst $X_c l \nu$ $X_u l \nu$ theo $\to$22%

You are here


Introduction
$2\times B\rightarrow X_u l\,\nu$
HQET
$b\rightarrow s\gamma$
$B\rightarrow\pi,\rho l\nu$
V_{ub}
CKM
V_{cb}
$B\rightarrow X_c l\nu$ moments
Form factors
$B\rightarrow D^* l\nu$
?

V_{ub} exclusive: $B \to ml\nu$



$d\Gamma(B\to ml\nu)/dq^2 \propto |V_{ub}|^2$
$K(p_m) F_m(q^2)^2$

- $K(p_m)$… kinematic factor
- $F_m(q^2)$…form factor function, depends on m

- Reconstruct $q^2=(p_l+p_\nu)^2$

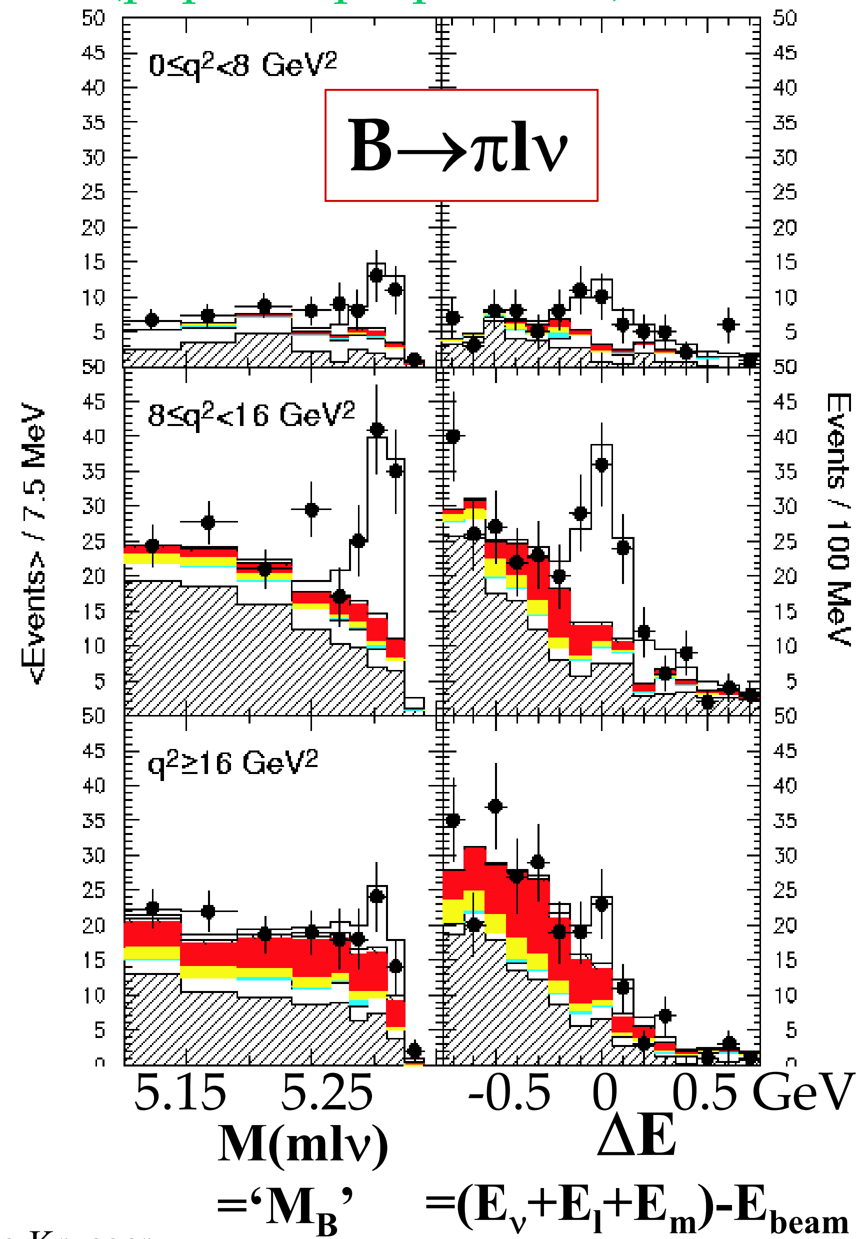
B→mlν yields

ν: $\overrightarrow{p_\nu} = \overrightarrow{P_{miss}}; E_\nu = \left|\overrightarrow{P_{miss}}\right|$

$p_l > 1.0[1.5]$GeV for πlν [ρlν]

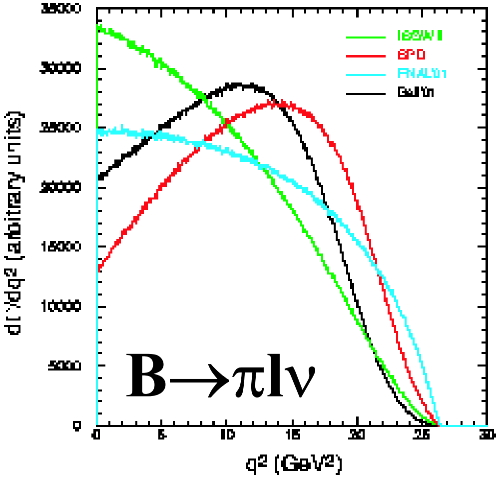
- Fit M_B and ΔE to get yield, all modes together, apply isospin constraints
  - πlν sees much feeddown from ρlν, ρlν does not have much from πlν
- Binning in q^2 reduces systematic uncertainty greatly
  - (variation of $\varepsilon(q^2)$, cross feed(q^2) over bin reduced)

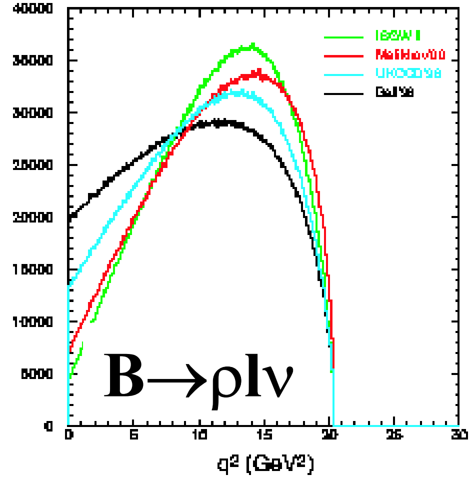
(paper in preparation)



Form factors and $|V_{ub}|$

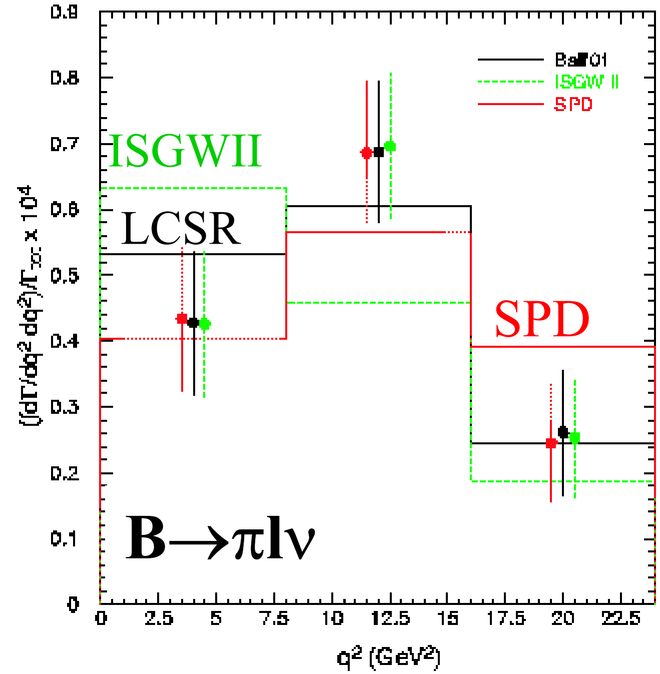
$d\Gamma/dq^2(q^2)$, q^2=0..30GeV^2:





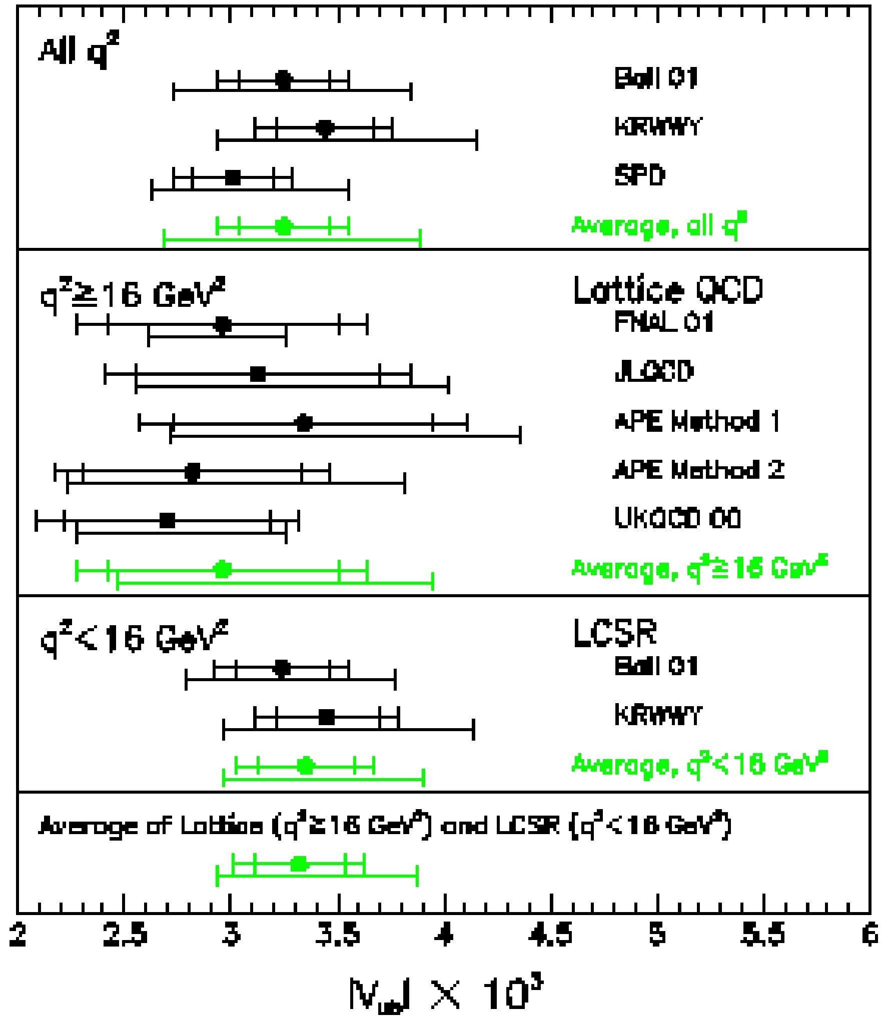
- One method: Fit with different form factor models
  - Fit quality ➢ discrimination among form factors!
  - Normalization ➢ $|V_{ub}|$
  - spread between models in B→πlν less than uncertainties of each model
- Or, use LCSR or LQCD calculations for form factors where applicable…

Branching fractions per q^2 interval:



Same for ρlν, but form factors differ more there

Extracting V_{ub} from $B \to \pi,\rho l\nu$ three different ways

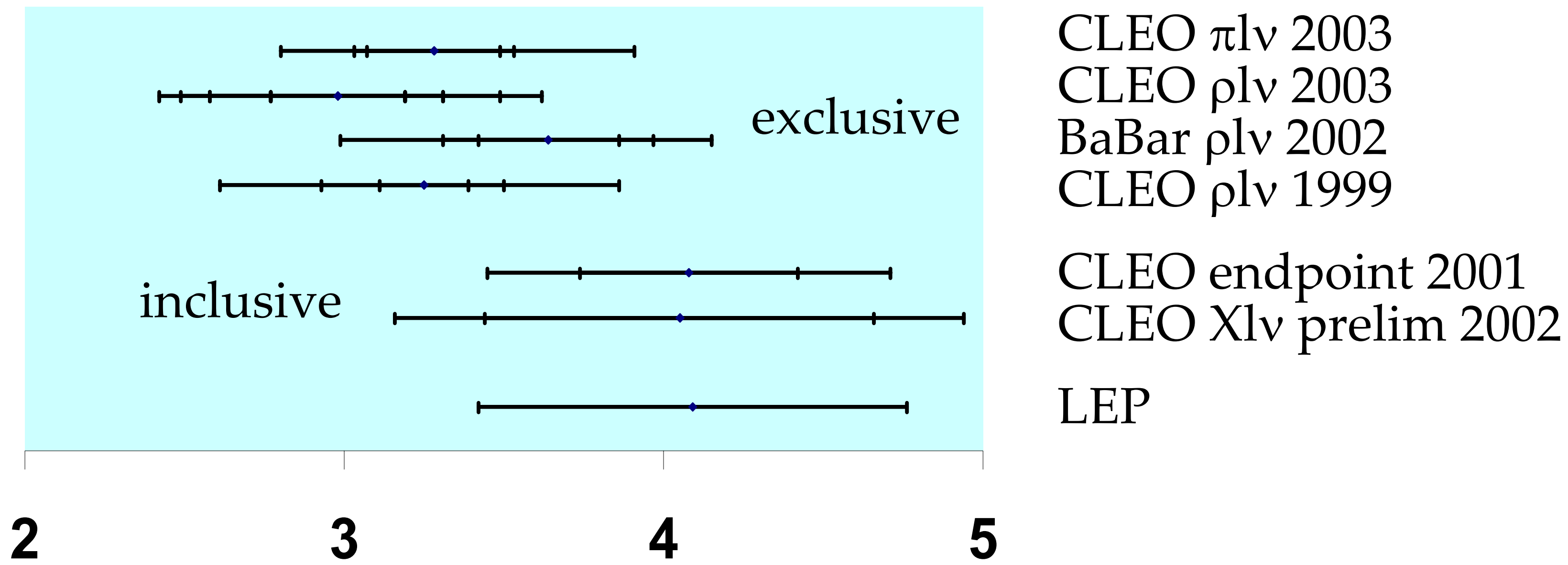


Form factors from:

1. Models
2. Lattice QCD (high q^2 only)
3. Light cone sum rules (low q^2 only)

- **CLEO result: Averaged values extracted using LQCD and LCSR**

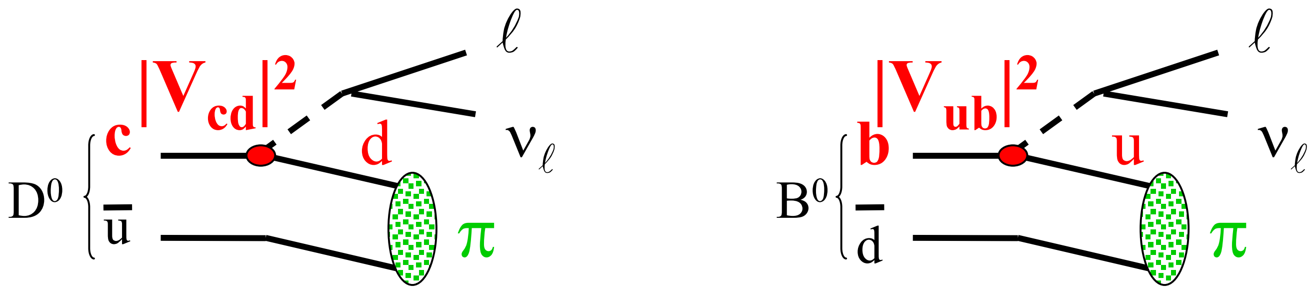
$|V_{ub}|$ comparison



$|V_{ub}|/10^{-3}$

Values are in good agreement.
Status: $\delta V_{ub}/V_{ub}$=14...20%

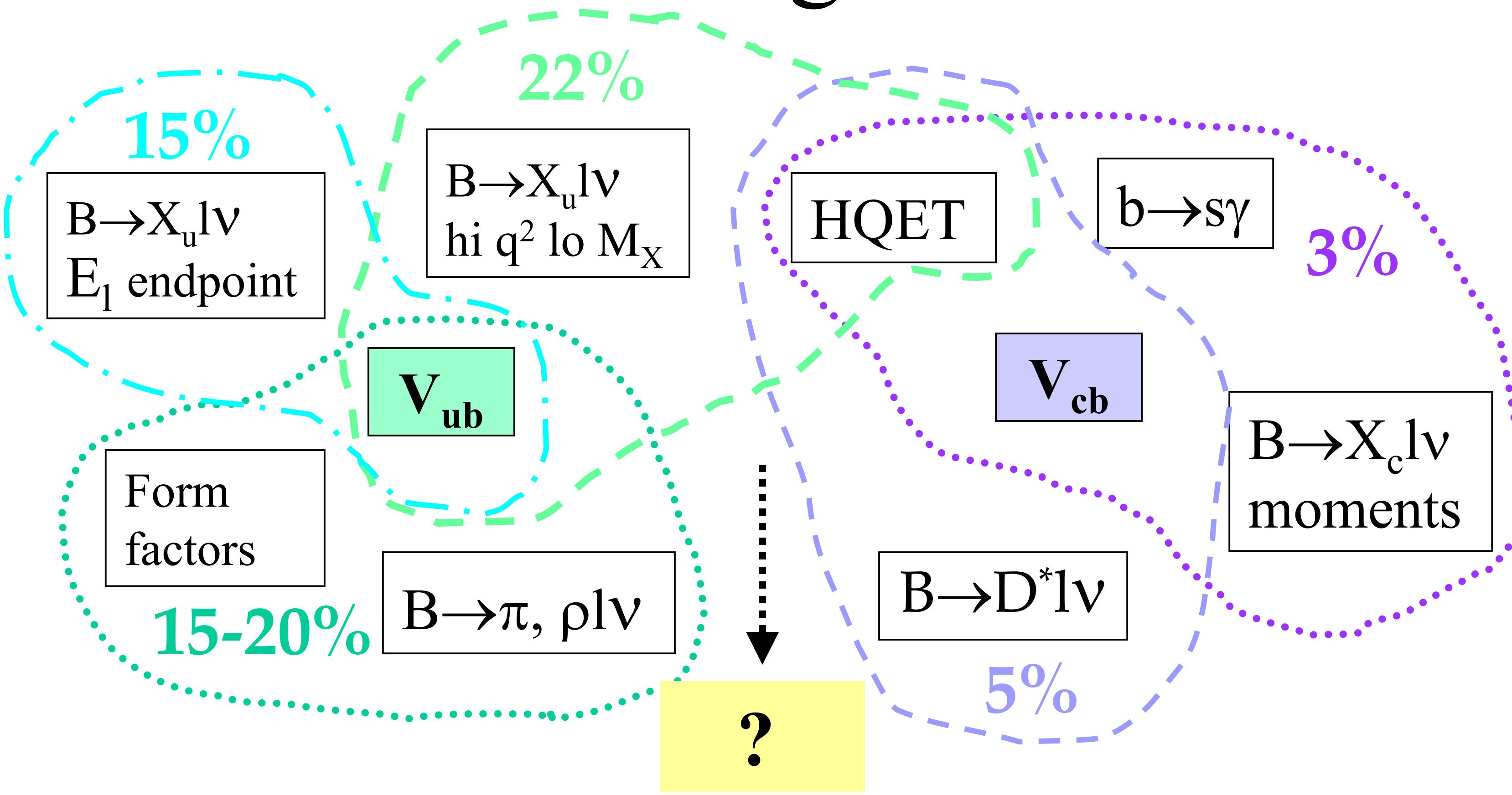
Another heavy-to-light transition: From $D \to \pi l \nu$ to $B \to \pi l \nu$



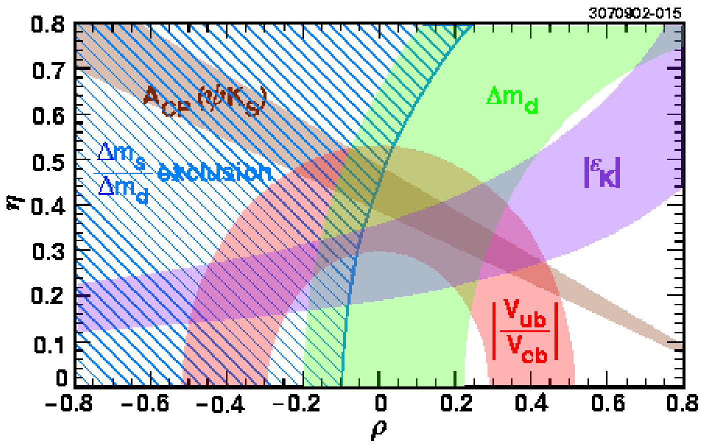
$\Gamma_{sl} = f(|V_{Hl}|^2$, form factor $f_+^{D,B\to\pi}$, kinematics):

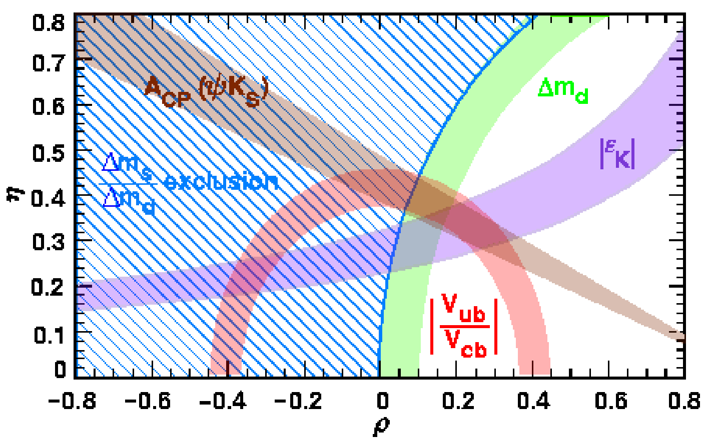
- $f_+^{D\to\pi} \leftrightarrow f_+^{B\to\pi}$ from HQET
- $|V_{cd}|$ known to 7%, extract $f_+^{D\to\pi}$ in D decays
- Principal background comes from $D\to Kl\nu$. CleoIII RICH particle ID should reduce this background substantially.
- Analysis underway

So far so good...



Where do we go from here?





- **B factories** will provide vast data samples
- More information at **new level of precision** on CKM matrix elements, CP violation etc to be expected soon
- Precision of CKM ME's **limited by theoretical understanding of strong interaction**
- **Theoretical tools** are being developed, but they need to be calibrated

Strong interaction and non-perturbative QCD

- **QED → QCD:** strong coupling and nonlinearity due to gluon self-coupling ⌧a new feature: **confinement**
- **Perturbative QCD** saved the day for high energies and has been extremely successful
- Confinement is a **low energy phenomenon** but an essential component of our physics picture → need to master this area too!!
- Theoretical tools available but must be verified, e.g. **lattice QCD**

Lattice version of QCD

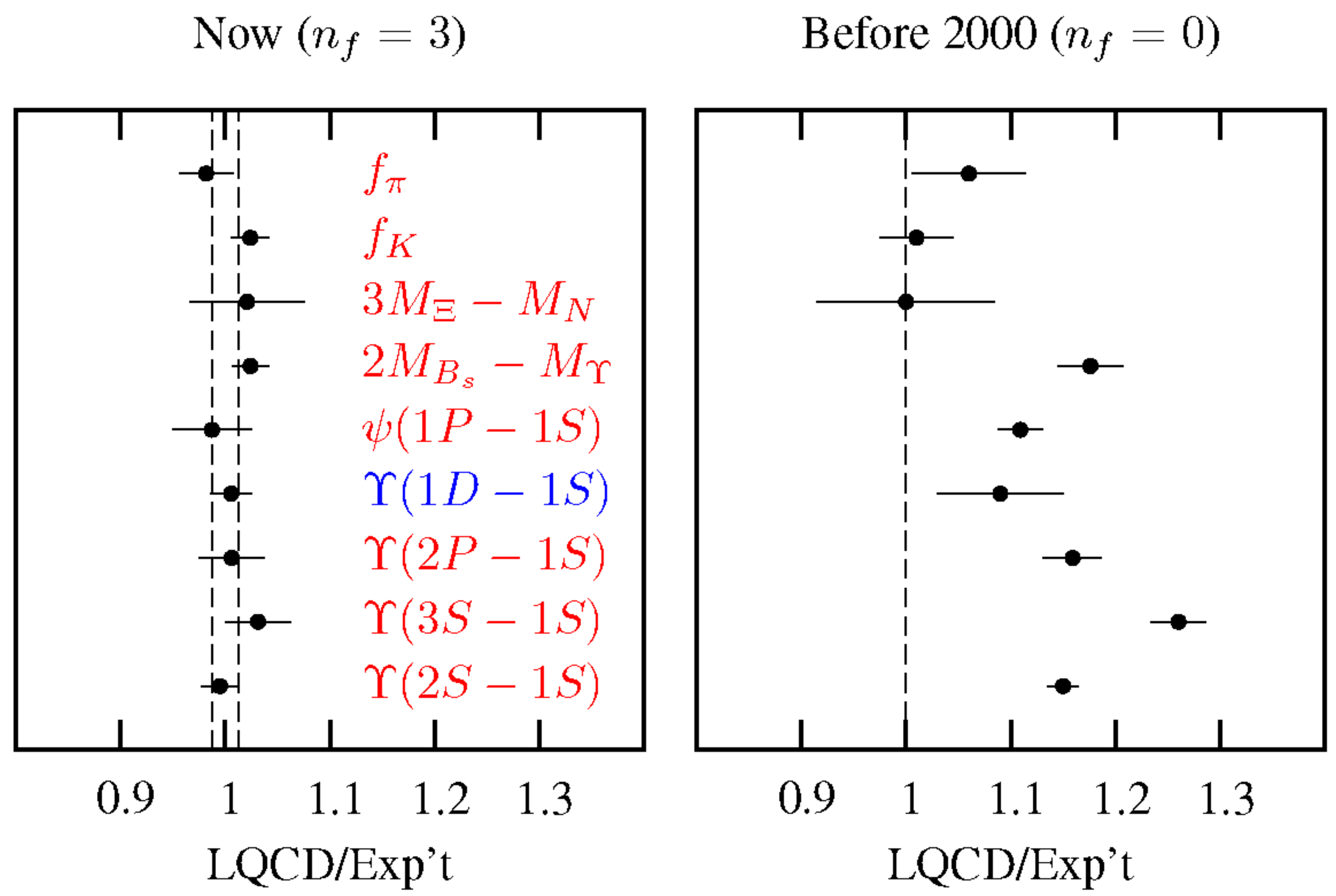
- The **only complete definition of QCD**: comprises pert. and non-perturbative aspects
- Also B factories welcome LQCD input, e.g. f_B
- Recent advances to allow **unquenched calculations** improved the precision of predictions from 15% down to the percent level, but…
- **Need data to calibrate!**

- Recent results (fall '02)
  - Tune m_u=m_d,m_s,m_c,m_b and α_S using m_π, m_K, m_Υ,m_ψ,ΔE_Υ(1P-1S), n_f=3, a=1/8fm
- Much more precise results (errors reduced 3-4x)
- remarkable agreement with experimental data

G.P. Lepage for HPQCD+MILC Collaborations (Preliminary Results)

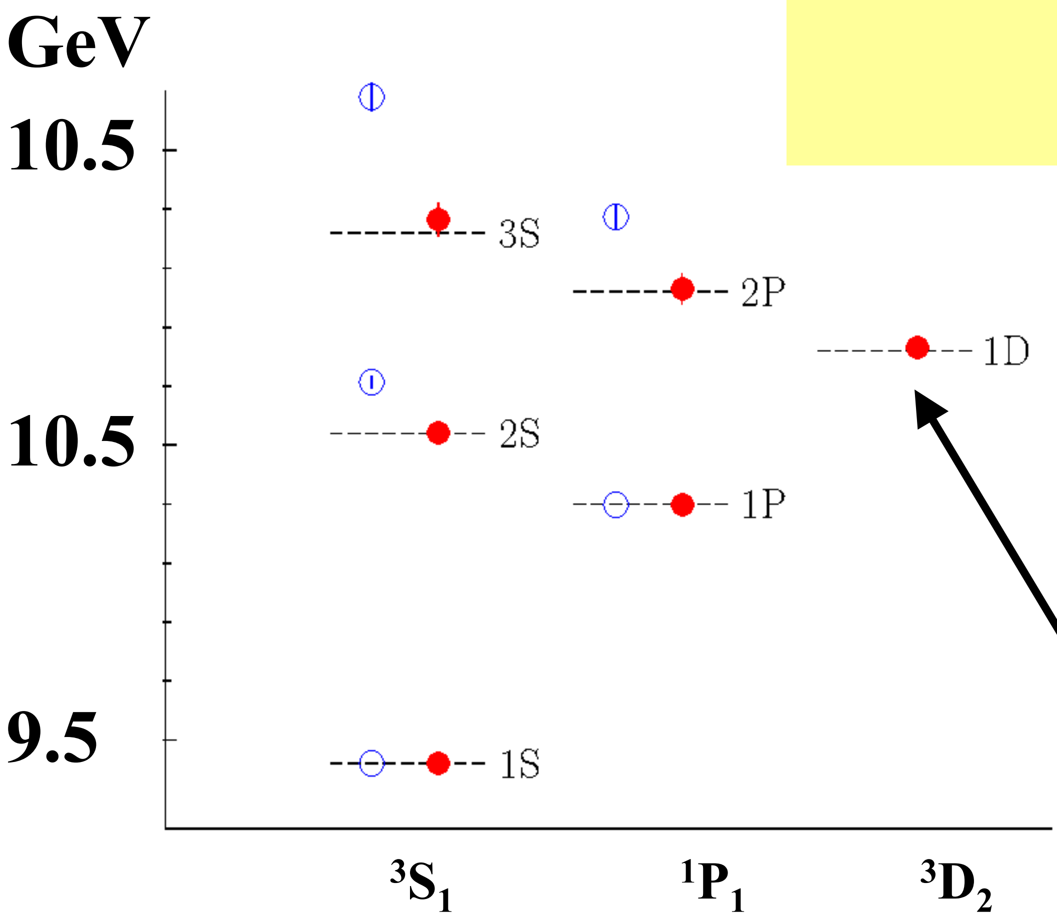
Recent LQCD results

⇒ New results: (lattice QCD)/(experiment) — no free parameters!



HPQCD+MILC: Very Preliminary

Recent LQCD results: ϒ spectrum



- - - Experiment

○ : Quenched MILC

● : 2+1 flavors MILC with $m_{u,d}=m_s/5$

(Recent CLEO result: Υ_2(1D), ICHEP02)

HPQCD: Davies, Gray et al. (2002)

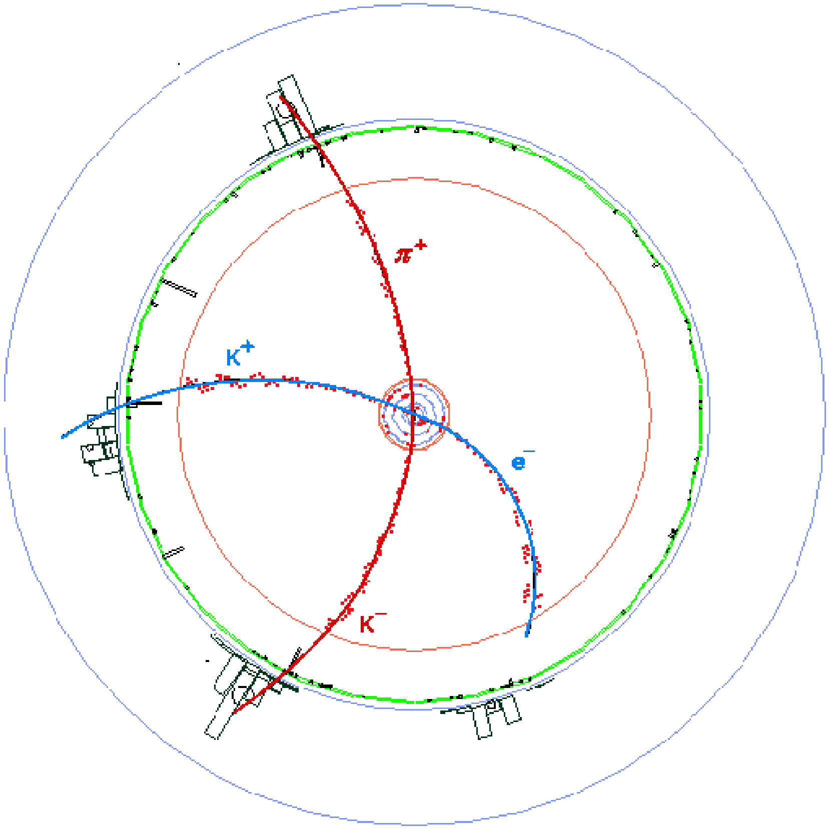
CLEO-c / CESR-c

Ref: "CLEO-c and CESR-c: A New Frontier of Weak and Strong Interactions" (CLNS 01/1742)

- **3 years of charm and QCD physics** (2003-2006)
  - ① CESR: add wigglers to enhance transverse cooling
  - ① CLEO: silicon vertex detector $\rightarrow$ inner drift chamber
  - ① Solenoid: 1.5 $\rightarrow$ 1 Tesla (compensation, reconstruction)
- **Υ(1,2,3S), 1-2fb^{-1} each**, finished in June 2002
  precision spectroscopy
  CLEO, ICHEP02: **Υ_2(1D)**
- **ψ(3700), 3fb^{-1}; ψ(4100), 3fb^{-1}; ψ(3100), 1fb^{-1}**
  orders of magnitude more than was available before (MarkIII, BESII)

Large samples of extremely clean events in an interesting energy region

A Cleo-c (MC) event



$D^0 \to K^- \pi^+$ $\bar{D}^0 \to K^+ e^- \nu$

- Clean events, low multiplicity
- Spherical event topology
- Good signal/bkd ratio
- ....

Cleo-c - a unique opportunity

- Calibration of LQCD tools such that they can be trusted when applied to b physics
- ~1% measurements of $|V_{cs}|$ and $|V_{cd}|$
- Direct Beyond the Standard Model searches unique to Cleo-c
- Sensitive searches of glueballs and exotic states

Vastly more low energy data	A modern detector	New theory tools

$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad}$

Unprecedented precision

Friday 2/7/03 14.33h:

--> Dear CLEO Colleagues,

We just received the following short announcement from Maury Tigner:

To CLEO, CESR and CHESS Colleagues

We learned this morning that the National Science Board, the governing board of the NSF, has approved the 5 year proposals of both LEPP and CHESS.

There will be a celebration in the Wilson Commons on Feb. 28

Needless to say, we are delighted that we can now move forward confidently with CLEO-c knowing that the project is approved!

David and Ian

Summary

- CLEO continues to contribute to a precise understanding of the SM:
  - $|V_{cb}|$
  - $|V_{ub}|$
- Confinement remains one of the challenges
- New tools are becoming available, but we need testing grounds:
  - Recent advances in Lattice QCD
  - Cleo-c is on its way
- More than ever, it is essential to combine knowledge from all areas to obtain the best possible results.