"Selected Topics in Semileptonic B Decays" or "Gearing up for the ~ 1% Challenge"

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We are witnessing B physics adding high accuracy to high sensitivity driven by

- magnificent experim. facilities challenging and thus inspiring
- theoretical technologies

➥ Justification for Super-B factory as 3rd generation facility

qualitatively different from B factories as 2nd genen. facility
higher statistics fi precision tool

- more accuracy … on CKM parameters V(ub), V(td)
- more decays … B Æ e/mn D, B Æ tn D, B Æ g X_q
- new territory … °(5s) Æ $B_s B_s$

no need to apply if important, yet hard measurements deter you!

can we answer the "1 % challenge"?

predict
measure
interprete
diagnose

} observables with ~O(1%) uncert.

assumptions justified on the $\mathcal{O}(10\%)$ accuracy level might no longer be adequate on the $\mathcal{O}(1\%)$ level!

Case study on V(ub) to illustrate the paradigm

The Menu

- |V(cb)|, |V(ub)| [|V(td)|]
- supporting measurements
  - moments, experim. cuts
  - g spectrum
- quality control
  - higher moments
  - B_d vs. B_u vs. B_s
  - D_J resonan. & Sum Rules
- New Physics & B Æ tn D

numbers & details

less important here

-- for they can & will change! --

emphasis on general strategy for high accuracy paradigm:

- build rich data base involving hard measurements
- work to overconstrain as much as possible

On the power of the OPE

- a host of observables expressed by a universal cast of Heavy Quark Parameters (=expect. values of local operators):

$$m_Q,\ m_p^2,\ m_G^2,\ r_D^3,\ r_{LS}^3,\ \ldots$$

memento: only 2 local operators in $O(1/m_Q^3)$!

- energy & mass moments yield HQP, which in turn can be used universally

- caveat: in general not a 1-to-1 correspondence

moments € HQP

➥ need linear combinations of moments

I |V(cb)|

3 methods

1. the `golden' way
2. the `gold-plated' way
3. the `Cinderella' story

(1.1) The golden way: G(B Æ l n X_c) `inclusive'

G(B Æ ln X_c) =F(V(cb),HQP:m_Q, m_p^2,...) ±1-2%,th.

Benson,Mannel, Uraltsev,IB, NuPhy. B665,367

limiting factor: perturb. correct. to nonpert. contrib.

Caveat: do not rely on expansion in $1/m_{ch}$!

➥ do not impose constraint

m_b-m_c= <M_B> - <M_D>+m_p^2($1/2m_{ch}$-$1/2m_b$)+nonlocal op.

can check it *a posteriori*

➥ $|V(cb)/0.042| = 1 - 0.65[m_b - 4.6\ GeV] - 0.61(m_c - 1.15\ GeV)$

$+ 0.06(m_G{}^2 - 0.35\ GeV^2) - 0.013(m_p{}^2 - 0.4$

$GeV^2)$

$- 0.1(r_D{}^3 - 0.12\ GeV^3) - 0.01\ (r_{LS}{}^3 + 0.15\ GeV^3)$

energy/had. mass moments Æ HQP

$M_1(E_l) = G^{-1}$Ú$dE_l\ E_l\ d\ G/d\ E_l$

$M_n(E_l) = G^{-1}$Ú$dE_l\ [E_l - M_1(E_l)]^n\ d\ G/d\ E_l\ ,\ n > 1$

$M_1(M_X) = G^{-1}$Ú$dM_X{}^2\ (M_X{}^2 - M_D{}^2)\ d\ G/dM_X{}^2$

$M_n(M_X) = G^{-1}$Ú$dM_X{}^2\ (M_X{}^2 - \langle M_X{}^2\rangle)^n\ d\ G/dM_X{}^2\ ,\ n > 1$

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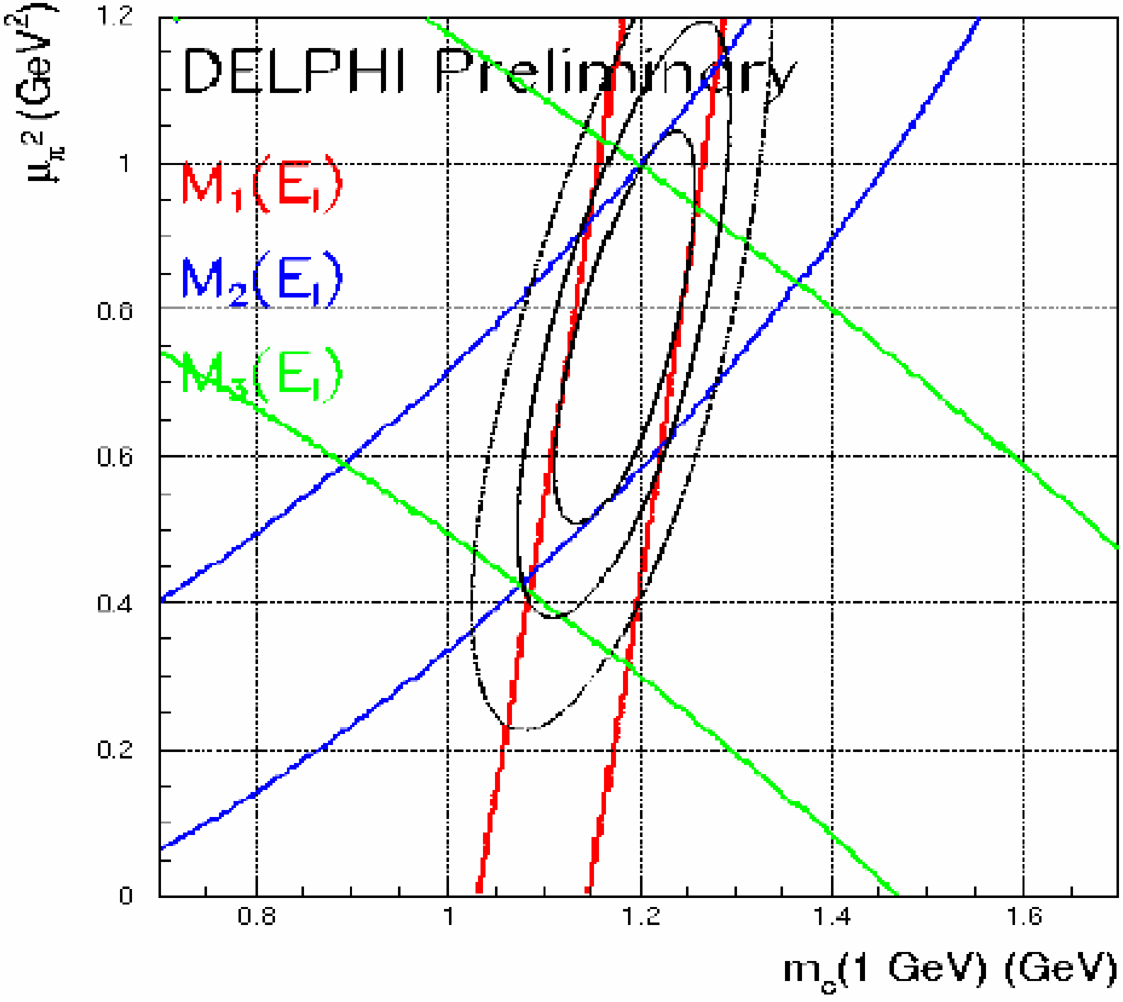
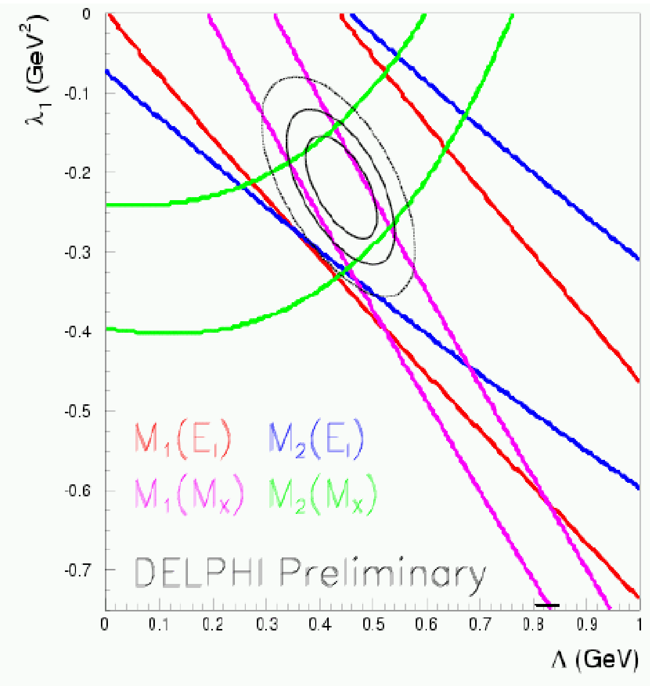




➥ need higher moments (reason # 1)

➥ $|V(cb)/0.042| = 1 - 0.65[m_b - 4.6\ GeV] - 0.61(m_c - 1.15\ GeV)$
$+ 0.06(m_G^2 - 0.35\ GeV^2) - 0.013(m_p^2 - 0.4\ GeV^2)$
$- 0.1(r_D^3 - 0.12\ GeV^3) - 0.01\ (r_{LS}^3 + 0.15\ GeV^3)$

$|V_{cb}| = 0.0416¥(1 \pm 0.017|_{exp} \pm 0.010|_{\Gamma(B)} \pm 0.015|_{HQP})$

Achille

"us"

vs. "dm_b ~ 2% implying $\delta|V_{cb}|$ > 5%"???

low moments depend on ~ same comb. of HQP!

$[.=F(m_b - 0.65m_c)]$

$[\Gamma_{part} µ m_b^2(m_b - m_c)^3]$

$|V(cb)/0.042| = 1 - 1.71\ [\langle E_l \rangle - 1.38\ GeV] - 0.06\ (m_c - 1.15\ GeV)$
$+ 0.08\ (m_G^2 - 0.35\ GeV^2) - 0.07(m_p^2 - 0.4\ GeV^2)$
$- 0.05(r_D^3 - 0.12\ GeV^3) - 0.005\ (r_{LS}^3 + 0.15\ GeV^3)$

"caveat emptor" : relation {moments ↔ HQP}

has not been scrutinized yet to same degree as

relation {$G_{SL}(B)$ ↔ HQP} (s.later)

(1.2) The gold-plated way: B Æ l n D* at zero recoil - `exclusive'

measure rate of B -> l n D*

- ☹ extrapolate to zero recoil & extract |V(cb) F_{D*} (0) |
- ☺ $F_{D*}(0) = 1 + \mathcal{O}(1/m_Q^2) + \mathcal{O}(a_s)$ normalized
- ☺ holds automatically for $m_b = m_c$
- ☹ expansion in $1/m_c$!

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

$F_{D*}(0) =$

- 0.89±0.08[0.05] Uraltsev et al.: $\mathcal{O}(1/m_Q^2)$
- 0.913±0.042 BaBar Book: not a consensus!
- 0.935 ± 0.03 first *prelim.* lattice: Hashimoto, Kronf. et al.
- $0.913\ ^{+0.024}_{-0.017}\ ^{+0.017}_{-0.030}$ 2nd *quenched* lattice: H,K et al. $\mathcal{O}(1/m_Q^3)$ [~ 0.89 at $\mathcal{O}(1/m_Q^2)$]

caveat: relies on expansion in $1/m_c$!

will use: $F_{D*}(0) = 0.90 \pm 0.05$ for convenience

$|F_{D*}(0)V(cb)| = 0.0367 \pm 0.0013$

➲ $|V(cb)|_{excl}$= 0.0408¥(1 ± $0.035|_{exp}$ ± $0.06|_{theor}$)

vs.

$|V(cb)|_{incl}$=0.0416¥(1±$0.017|_{exp}$±$0.010|_{\Gamma(B)}$±$0.015|_{HQP}$)

☺ full agreement with different systematics!

☹ theor. "brickwall" for $|V(cb)|_{excl}$: expansion in $1/m_c$!

(1.3) A `Cinderella' story in the making? B Æ ln D -`exclusive' II

B Æ l n D seen as `poor relative' of B Æ l n D *

- $F_{BÆD}(0)$ has $1/m_c$ term -- unlike for $F_{BÆD^*}(0)$
- $F_{BÆD}(0)$ -- unlike $F_{BÆD^*}(0)$ -- not normal. to unity for m_Q Æ • another `cinderella' story in the making?

BPS limit as `good fairy'

if $\mu_\pi^2=\mu_G^2$: $\sigma \bullet \pi|B\rangle=0$, $\rho^2=3/4$

➥ FF $f_-(q^2)= -(M_B-M_D)/(M_B+M_D)\, f_+(q^2)$ modif. by pert. corr., unaffect. by power corrections

in real QCD $\mu_\pi^2 - \mu_G^2 \ll \mu_\pi^2$, $\rho^2 \approx 3/4$

expansion in $\beta=[3(\rho^2-3/4)]^{1/2} = 3\,[\Sigma_n|\tau^{(n)}_{1/2}|^2]^{1/2}$

irreducible $df_+(0) \sim \exp(-2m_c/\mu_{had}) \sim$ few %

Program:

❶ extract |V(cb)| from B Æ e/m n D

❷ compare with `true' |V(cb)| from G_{SL}(B)

❸ if successful, use it for B Æ t n D (2nd FF!)

[hadronic FF does not drop out from G(B Æ t n D)/ G(B Æ m n D) !]

❹ check for New Physics contrib. to B Æ t n D (Higgs-X)

II |V(ub)|

Inclusive method

☺ expansion in $1/m_b$ better

☺ purely perturb. contributions better known

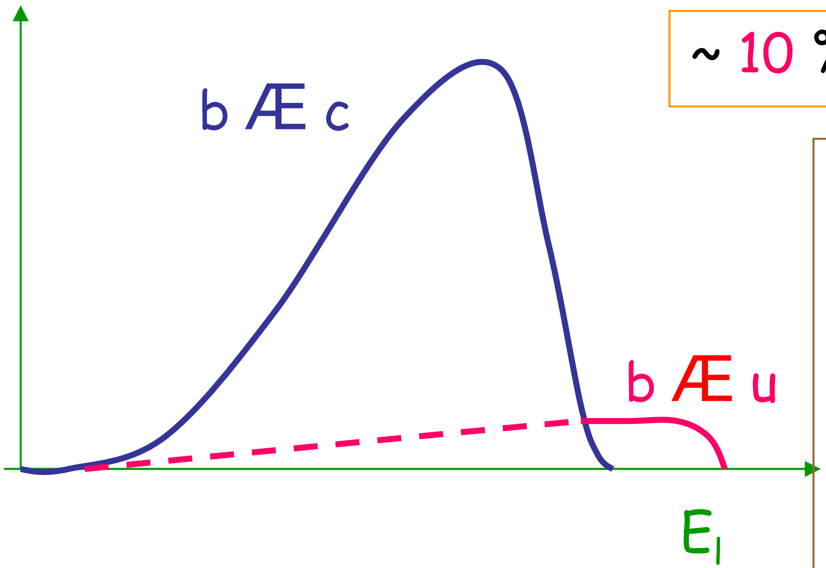
😐 need m_b rather than m_b - 0.65 m_c

➥ need higher moments (reason # 2)

☹ no HQS in final state, no SV Sum Rules

☹ experimentally much harder

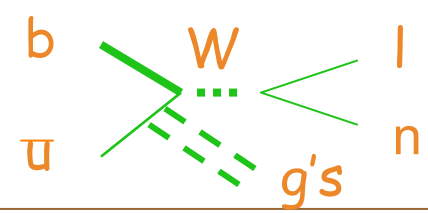
(2.1) Lepton Energy Endpoint Spectrum



~ 10 % of signal accessible!

- model dependance can be reduced
  inferring shape function from B Æ g X spectrum but far from eliminated:
  - subleading correct. to shape fction
  + shape fct(bÆgs) = shape fct(bÆlnu)

    + $\mathcal{O}(1/m_b)$
  - endpoint different for B_d and B^+ due to WA! Uralt., IB '94



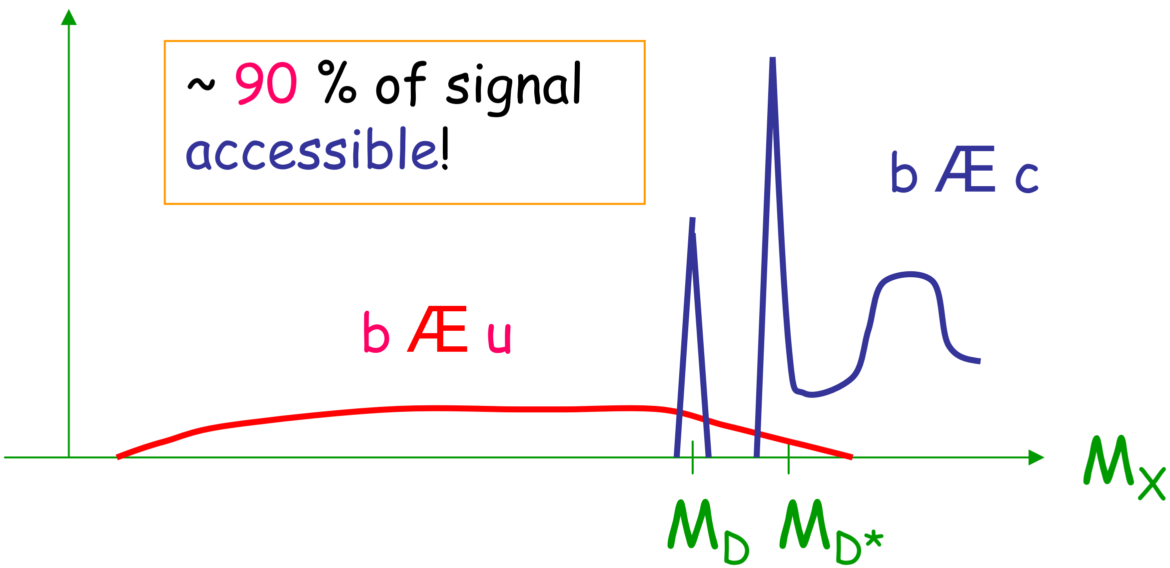
- expect sizeable violations to local duality

➥ will not be a precision extraction of |V(ub)|!

(2.2) Hadronic Recoil Mass Spectrum

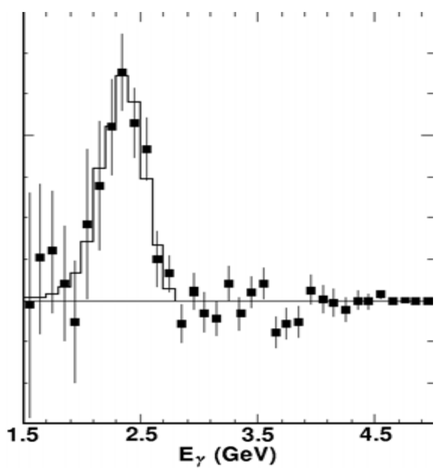
partially integrat. had. recoil mass spectrum

Ú $dM_X ds/dM_X$ (B Æ l n X) with $M_{X,max} < M_D$

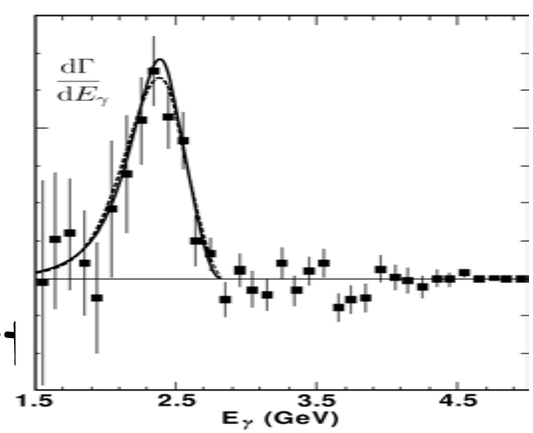


mild dependance on cut-off $M_{X,max}$ for $M_{X,max} \sim 1.6$ GeV least reliable part theoretically: low q^2 (q = lepton pair mom.)

- cut low q^2 Bauer et al.
  - ☺ can be done
  - ☹ lose constraints due to Sum Rules
  - ☹ retain < 50 % of rate -- duality viol.?
- infer from recoil mass spectrum in **B Æ g X** Uraltsev, IB
  - ☹ need photon spectrum below 2 GeV - say 1.8 < E $_{\mathbf{g}}$<2 GeV



~ 5 % att



III |V(td)|

usual avenues:

- K^+ **Æ** $\mathbf{p^+}$ **n n** best -- theoretically
- B **Æ g r/w** vs. B **Æ g** K* control over long distance dynamics?
- B_s - $\bar{B}_s$ vs. B_d - $\bar{B}_d$ oscillations

newcomer (?): differentiate between

B **Æ g** X_d vs. B **Æ g** X_s

to extract |V(td)/V(ts)|

☹ experimentally very challenging

☺ theoretically clean --

😐 within the SM!

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

IV Impact of Experimental Cuts

Experimental cuts on energy etc. applied for practical reasons

yet they degrade \`hardness' Q of transition

∃ \`exponential' contributions $\exp[-cQ/m_{had}]$ missed in usual OPE expressions

- quite irrelevant for $Q \gg m_{had}$
- yet relevant for $Q \sim m_{had}$!

for B Æ g X_q: $Q = m_b - 2\,E_{cut}$
e.g.: for $E_{cut} \sim 2$ GeV, $Q \sim 1$ GeV !

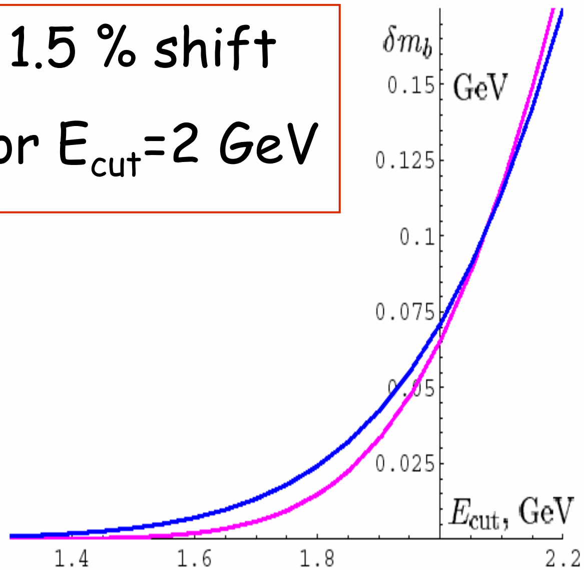
Pilot study (Uraltsev, IB)

earlier work by C. Bauer

- considers very different effects
- addresses theor. uncertaint., not biases!

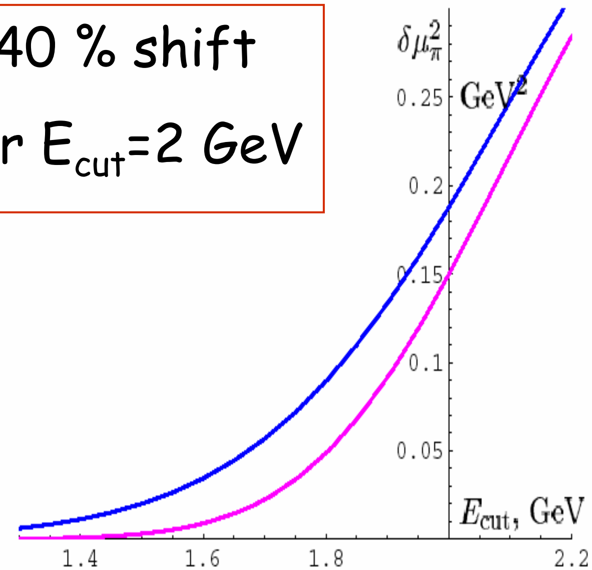
~ 1.5 % shift

for E_{cut}=2 GeV



~ 40 % shift

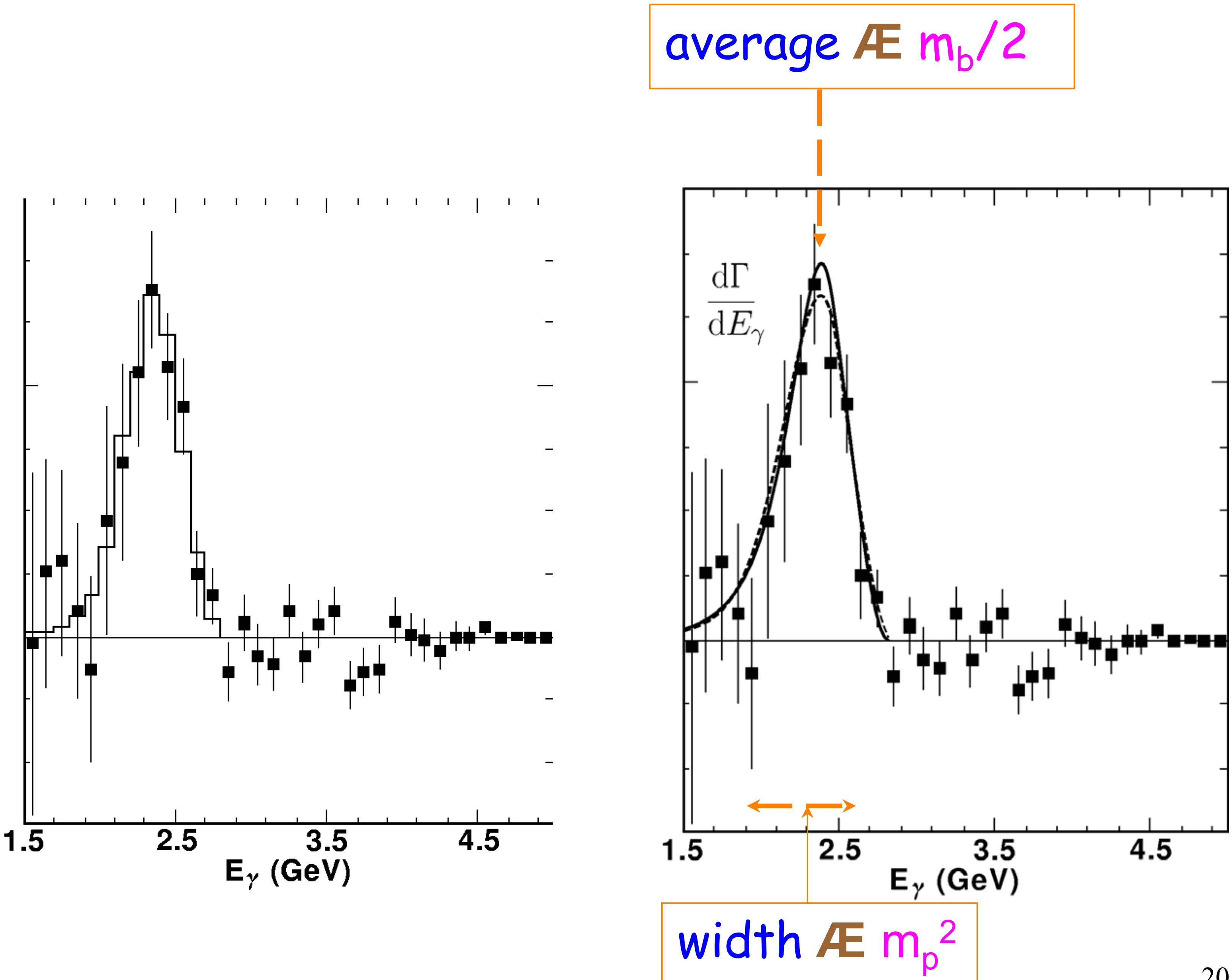
for E_{cut}=2 GeV



absolute bias due to experim. cut

2 different ansaetze for distribution function

[curves shown for m_b=4.6 GeV, μ_π^2 = 0.45 GeV^2; bias depends on HQP]



average Æ $m_b/2$
$\frac{d\Gamma}{dE_\gamma}$
1.5
2.5
3.5
4.5
E_γ (GeV)
1.5
2.5
3.5
4.5
E_γ (GeV)
width Æ m_p^2

terms ~ $O(1/m_Q^3)$ irrelevant for this analysis

- only 3 dimensional parameters: m_b, μ_π^2, $Q = m_b - 2 E_{cut}$
- simple scaling behaviour arises

Don Benson

I have created six tables for $\frac{\delta m_b}{\sqrt{\mu_\pi^2}}$ versus $\frac{Q}{\sqrt{\mu_\pi^2}}$. There are three tables for each different ansatz. The three tables are for $\frac{\mu_\pi^2}{\Lambda^2} = 0.7, 1.0, 1.3$. I have plotted the tables for you to see.

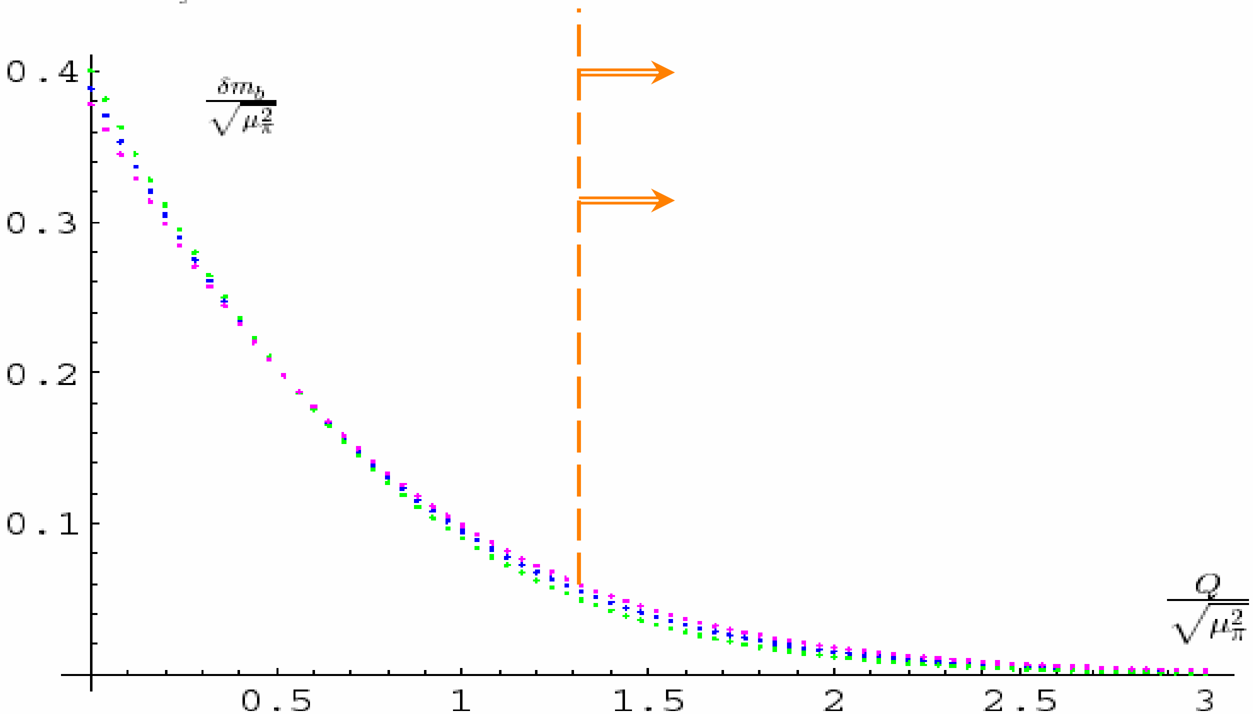


Figure 1: $\frac{\delta m_b}{\sqrt{\mu_\pi^2}}$ versus $\frac{Q}{\sqrt{\mu_\pi^2}}$ using the e^{-cx} distribution function. The blue line gives the bias for $\frac{\mu_\pi^2}{\Lambda^2} = 1$. The purple and green lines show the variation in the ratio as $\frac{\mu_\pi^2}{\Lambda^2}$ is varied over $\pm 30\%$.

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TIFF (Uncompressed) decompressor
are needed to see this picture.

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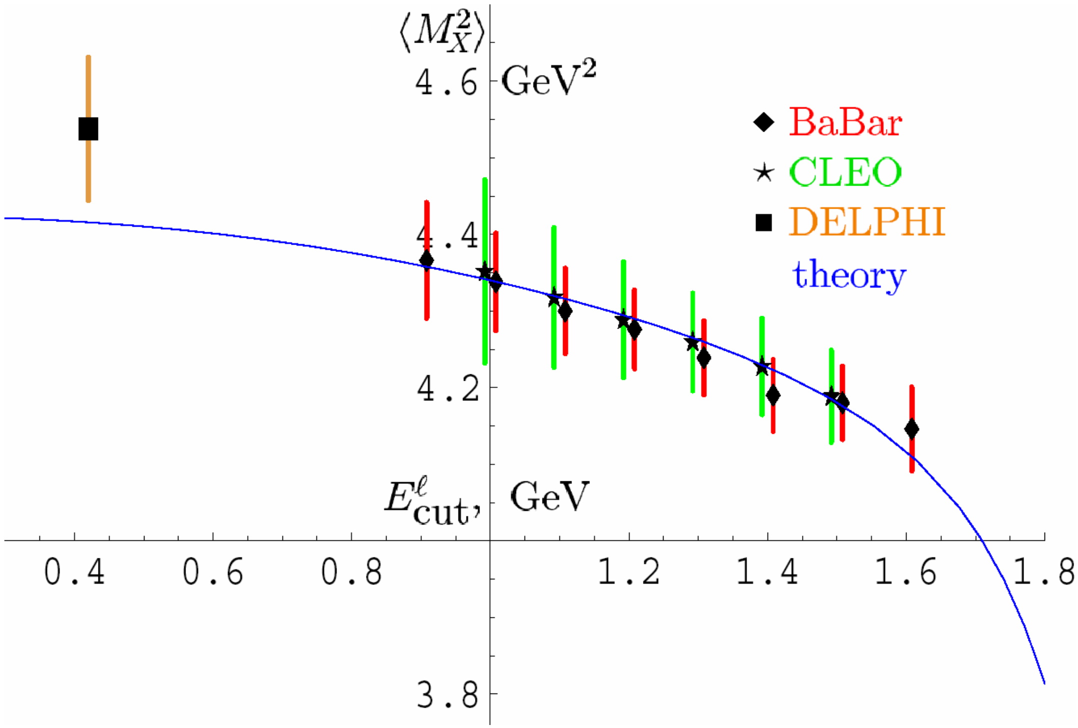

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hadronic mass moments in B Æl n X_c

➥ encouraging, yet more work needed

Lessons:

- keep the cuts as low as possible
- bias in the meas. moments induced by cuts
  - ☞ can be corrected for
  - ☞ not a pretext for inflating theor. uncert.
- moments meas. as fction of cuts: important cross check!

V Quality Control

Overconstraints most powerful protection against ignorance

Lenin's dictum: "Trust is good -- control is better!"

- measure higher (2nd and 3rd) moments
- of different types
- keep energy cuts as low as possible
- yet analyze moments as function of (reasonable) cuts
- final states in B Æ l ν $D(s_q = 1/2 \text{ or } 3/2)$

prod. of diff. $D(s_q)$ ´ HQP

SSV sum rules

- ☞ $r^2(m) - 1/4 = S_n |t_{1/2}^{(n)}|^2 + 2\, S_m |t_{3/2}^{(m)}|^2$
- ☞ $1/2 = -2\, S_n |t_{1/2}^{(n)}|^2 + S_m |t_{3/2}^{(m)}|^2$
- ☞ $\overline{L}(m) = 2\,(S_n e_n |t_{1/2}^{(n)}|^2 + 2\, S_m e_m |t_{3/2}^{(m)}|^2)$
- ☞ $m^2_p(m)/3 = S_n e_n^2 |t_{1/2}^{(n)}|^2 + 2\, S_m e_m^2 |t_{3/2}^{(m)}|^2$
- ☞ $m^2_G(m)/3 = -2\, S_n e_n^2 |t_{1/2}^{(n)}|^2 + 2 S_m e_m^2 |t_{3/2}^{(m)}|^2$
- ☞ …… where: $t_{1/2}$ & $t_{3/2}$ denote transition amplitudes for
  B Æ l ν $D(s_q = 1/2$ or $3/2)$
  with excitation energy $e_k = M(B) - M(D_k)$, e_k £ m

➥ rigorous inequalities + experim. constraints

SV SR strongly suggested broad $D(s_q=3/2)$ to lie below 2400 MeV -- contrary to usual interpretation of data.

BaBar's discovery of D_{sJ} reopened issue!

- extract CKM parameters separately for

  SL B_u vs. B_d vs. B_s decays

  as a check on quark-hadron duality

rationale: nearby & narrow resonance could modify rate

- b Æ c: DI = 0

  - resonance could affect B_d & B_u Æ l n X_c -- but equally

new territory

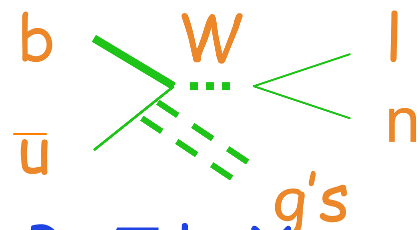
B_s Æ l n D_s(*), G $_{SL}(B_s)$ would provide test!

not doable at had.coll.(?)

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

b Æ u: DI = 1/2

☞ ds(B_d Æ ln X_u)/dE_l π ds(B_u Æ ln X_u)/dE_l in $\mathcal{O}(1/m_b^3)$!



☞ B_d Æ ln X_u vs. B_u Æ ln X_u

I_f= [1,+1] vs I_f= [1,0]+[0,0]

➥ affected differently by a resonance

VI Summary

1 - 5 % accuracy level in

- |V(cb)| achieved
- |V(ub)| not utopian
- |V(td)|

requirements

- theoretical analysis challenged and fed by
- rich data base
- that requires > 0.5 ab^{-1} data from B factory
- with constant re-evaluation of assumptions & approxim.

e.g.:

to extract a value for |V(ub)| with an error estimate that can be defended need

- measurement of Ú $dM_X ds/dM_X$ (B Æ l n X) with $M_{X,max} < M_D$
- preferably for B_d & B_u separately and the
- photon spectrum in B Æ g X with 1.8 < E_g < 2 GeV

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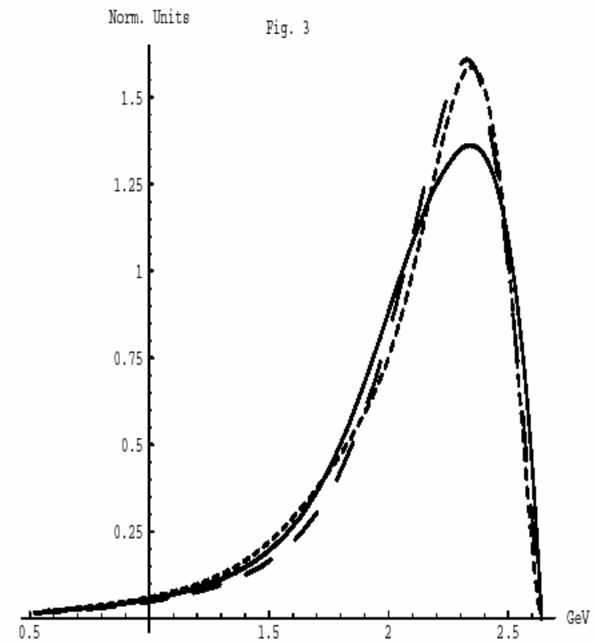

Norm. Units
Fig. 3
1.5
1.25
1
0.75
0.5
0.25
0.5
1.5
2
2.5
GeV