Leptonic and rare decays

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Section overview

- Discussion at SLAC workshop regarding which modes belonged where...

C The results and their interpretation

11. B physics
    a. Vub and Vcb
    b. Vtd and Vts
    c. Hadronic B to charm decays
    d. Charmless B decays
    e. Mixing/EPR correlations
    f. beta (a.k.a. phi_1)
    g. alpha (a.k.a. phi_2)
    h. gamma (a.k.a. phi_3)
    i. CPT violation
    j. Radiative and EW penguin decays
    k. Leptonic Decays and B to D(*) tau nu
    l. rare, exotic and forbidden decays
    m. Baryonic B decays
12. Quarkonium physics

- ...some subsequent rearranging of content, with section was explicitly split into two separate subsections
  - "rare" leptonic and semileptonic modes
  - other rare non-hadronic decays
- $B \to l\nu$ and $B \to D^{(*)}\tau\nu$ use similar experimental methodology and similar new physics sensitivity
- $B \to K\nu\nu$ belongs with $B \to K l^+ l^-$, $b \to s\gamma$ etc.
- $B^0 \to l^+ l^-$, $B^0 \to \gamma\gamma$, $B^0 \to$ invisible, LFV modes, etc. treated separately

Section Outline

1.1 B physics — Initial page guestimates

...

K. Leptonic Decays and $B^+ \to D^{(*)}\tau^+\nu$

- I. General theory overview and motivation — (short)
- II. $B^+ \to l^+\nu$ (l = e, μ, τ)
  - II.i Theory — (2)
  - II.ii $B^+ \to \tau^+\nu$ measurements — (3)
  - II.iii $B^+ \to l^+\nu$ (l = e, μ) measurements — (2)
  - II.iv $B^+ \to l^+\nu\gamma$ measurements — (1)
  - II.v Interpretation of results — (2)
- III. $B \to D^{(*)}\tau^+\nu$
  - III.i Theory — (3)
  - III.ii Methodology and experimental results — (7)
- IV. Discussion, interpretation and future prospects — (2)

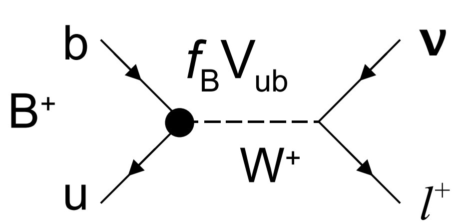
← Radiative/EW section here?

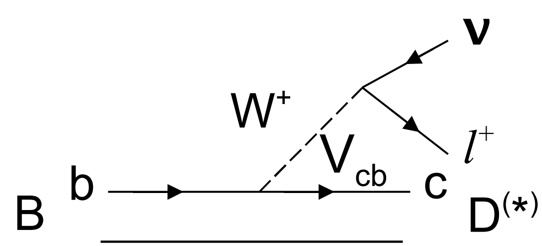
L. Rare, Exotic and Forbidden Decays

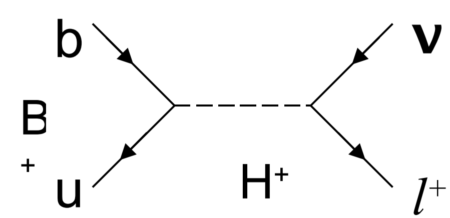
- I. Motivation and theory overview — (short)
- II. Methodology — (short)
- III. $B^0 \to l^+l^-$ (also $\tau^+\tau^-$ and $l^+l^-\gamma$) — (3)
- IV. $B^0 \to \gamma\gamma$ (maybe in radiative/EW section?) — (1)
- V. $B^0 \to$ invisible — (1)
- VI. Lepton number/flavor violating modes — (2)

Detailed section content

- Tree level processes in SM with sensitivity to V_{ub} and V_{cb}.
  - In $B^+ \rightarrow l^+ \nu$ hadronic effects encapsulated in decay constant, while $B^+ \rightarrow D^{(*)} \tau^+ \nu$ has form factor uncertainties.
  - In both cases, new physics sensitivity (e.g. tree-level H^+ contribution) can arise due to suppressed SM rate and 3rd generation coupling
- $B^+ \rightarrow l^+ \nu$ is theoretically clean but experimentally difficult. $B^+ \rightarrow D^{(*)} \tau^+ \nu$ has advantage of more observables, but also larger theory uncertainties







Leptonic decays

II. $B^+ \to l^+\nu$ (l = e, μ, τ)
II.i Theory

- SM theory formalism:

$$\mathcal{B}r(B^+ \to \ell^+\nu_\ell) = \frac{G_f^2}{8\pi}|V_{ub}|^2 f_B^2 m_B m_\ell^2 \tau_B \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2$$

  – importance of **f_B and V_{ub}**; helicity suppression yields larger $B^+ \to \tau^+\nu$ BF, but more experimentally difficult than e, μ modes

- Effect of non-SM contributions, including H^+ and also possibility of LFV (Paradisi/Isidori).

$$B(B^+ \to l^+\nu)^{2HDM} = B(B^+ \to l^+\nu)^{SM} \times [1 - \tan^2\beta\,(m_B^2/m_{H^+}^2)]^2$$

W.S.Hou Phys. Rev. D48, 2342 (1993)

- Probably need to also present here some discussion of soft radiation and the relation between $B^+ \to l^+\nu$ and $B^+ \to l^+\nu\gamma$ (E. Kou et al.)

$B^+ \to \tau^+ \nu$

II.ii $B^+ \to \tau^+ \nu$ measurements

- There is a subsection under "Tools" which will present a description of the tag reconstruction method
  - focus of this section will be on issues specific to these analyses
- BABAR and Belle both perform separate “hadronic” and “semileptonic” tag analyses, so four independent measurements

BABAR refs:

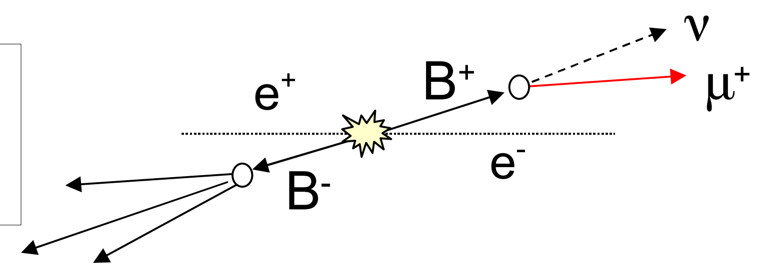
PRD-RC 77, 011107 (2008)	Hadronic tag (to be updated to full data set)
PRD-RC 81, 051101 (2010)	SL tag (final)

Belle refs:

PRL 97, 251802 (2006)	Hadronic tag (to be updated to full data set)
arXiv:0809.3834 (2008)	SL tag (to be submitted)

$B^+ \to l^+\nu$

II.iii $B^+ \to l^+\nu$ (l = e, μ) measurements



- "Usual" method is an inclusive search based on the high-p lepton, however BABAR has published (and Belle is working on) "tagged" analyses using methodology similar to $B^+ \to \tau^+\nu$

⇒ need a short explanation of what the conceptual difference is between the "inclusive" and "tagged" methods

BABAR refs:

PRD-RC 79, 091101 (2009) (full dataset, inclusive)

PRD-RC 77, 091104 (2008) (hadronic tag)

PRD-RC 81, 051101 (2010) (SL tag)

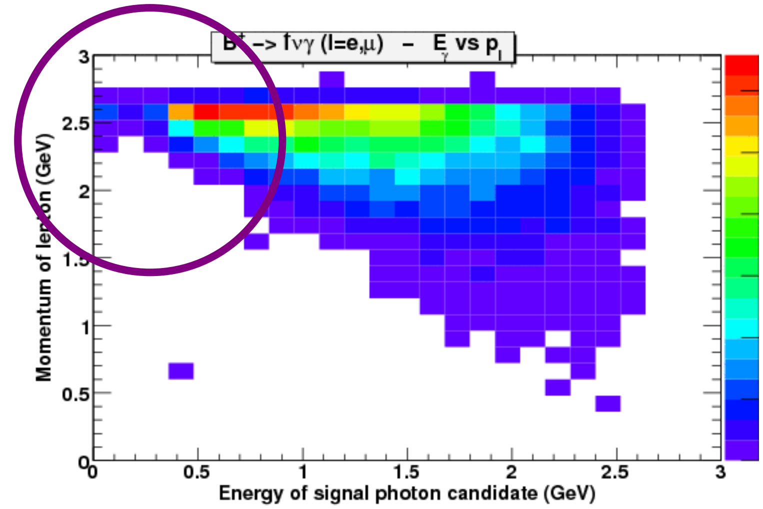
Belle refs:

PLB 647, 67 (2007) (inclusive; update in progress)

Tagged analyses in progress, results expected in ~six months

$B^+ \to l^+\nu\gamma$

II.iv $B^+ \to l^+\nu\gamma$ measurements



- Radiation of hard photon removes helicity suppression of $B^+ \to l^+\nu$ modes with consequence that e, μ modes are experimentally accessible

$$\Gamma(B^+ \to l^+\nu\gamma) = \alpha \frac{G_F^2 |V_{ub}|^2 m_B^5}{288\pi^2} f_B^2 \left(\frac{Q_u}{\lambda_B} - \frac{Q_b}{m_b}\right)^2$$

In practice, can extract λ_B which is related to B light cone wave function

G. Korchemsky, D. Pirjol, T.-M. Yan
Phys. Rev. D61:114510, 2000. (hep-ph/9911427)

$B^+ \to l^+ \nu \gamma$

II.iv $B^+ \to l^+ \nu \gamma$ measurements

- B factories seem to have had difficulties with this mode...

  BABAR refs:

  PRD-RC 80, 111105 (2009) hadronic tag, full dataset

  0704.1478 [hep-ex] inclusive search, likely will never be published

  Belle ref:

  arXiv:hep-ex/0408132 (2004) only a very old (2004) prelim

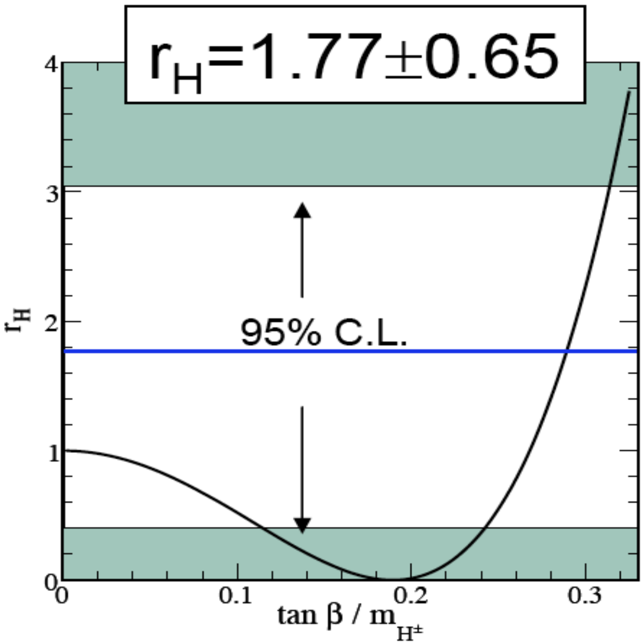
  - Experimental issue has been understanding of continuum (untagged) and exclusive semileptonic B background (tagged

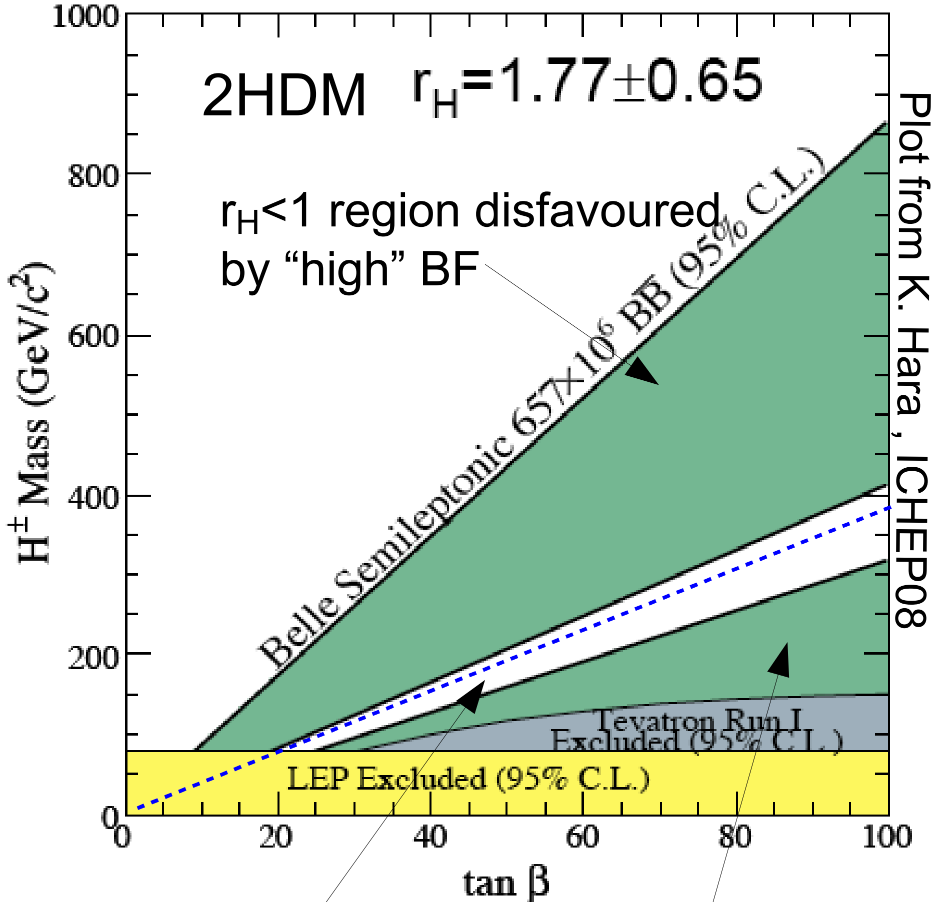
- discussion should include some comparison of consistency with respect to $B^+ \to l^+ \nu$, comments on extraction of QCD parameters and (maybe) discussion of effect of $B^+ \to \pi^0 l^+ \nu$ form factors on background determination

New Physics Constraints

II.v Interpretation of results

- Interpretation of measurements in context of SM and new physics models (2HDM Type II H^+)
  - effect of SUSY corrections (i.e. model dependence of bounds)





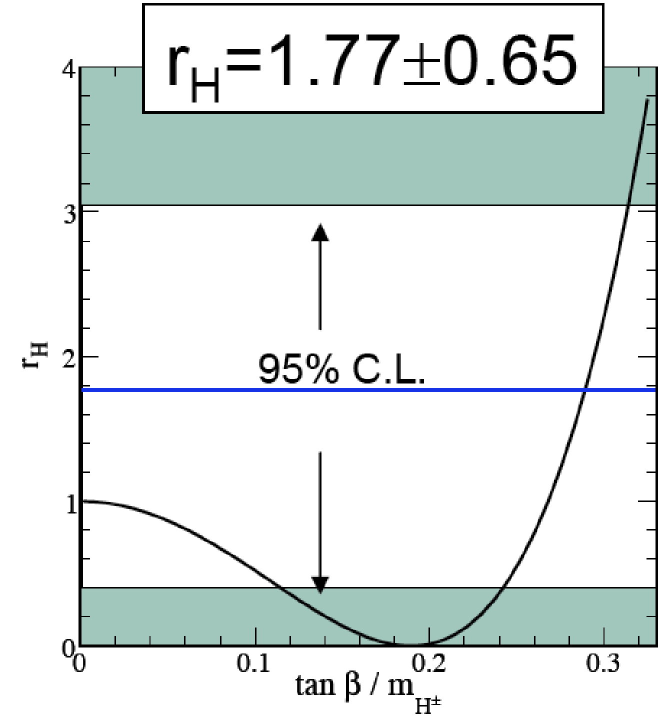
"Pathological" case where Higgs contribution is exactly double the SM contribution

Large - r_H region (ruled out by BF upper limits)

New Physics Constraints

II.v Interpretation of results

- Would be interesting to compare with $B^+ \to \tau^+ \nu$; current limits on $B^+ \to \mu^+ \nu$ are approaching SM sensitivity, hence might be some tension with “high” value of $B^+ \to \tau^+ \nu$
- Ratio of leptonic branching fractions very interesting both as a consistency test and as a new physics test for LFV



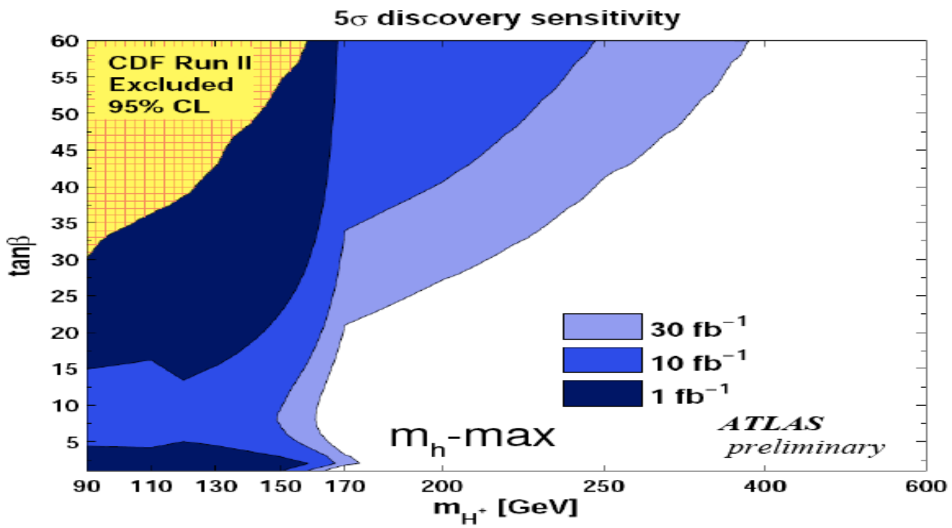
$$\left(R_B^{\ell/\tau}\right)^{\mathrm{MSSM}}_{\mathrm{LFV}} = \left(R_B^{\ell/\tau}\right)^{\mathrm{SM}} \left[1 + \frac{1}{R_{B\tau\nu}} \left(\frac{m_B^4}{M_{H\pm}^4}\right) \left(\frac{m_\tau^2}{m_\ell^2}\right) |\Delta_R^{\tau\ell}|^2 \frac{\tan^6\beta}{(1+\epsilon_0 \tan\beta)^2}\right]$$

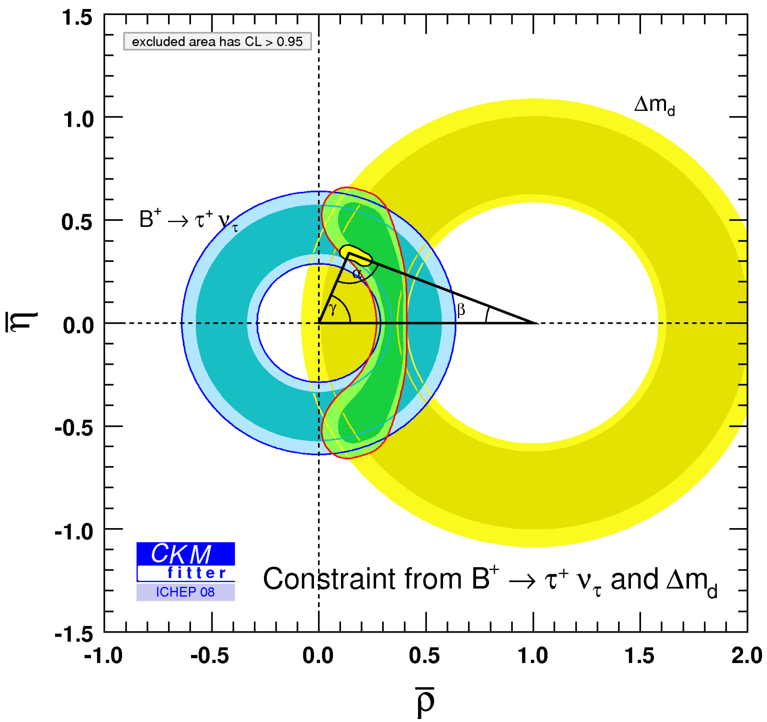
G. Isidori and P. Paradisi hep-ph/0605012
A. Masiero, P. Paradisi and R. Petronzio hep-ph/0511289

Discussion/prospects

II.v Interpretation of results

- Discussion of tension with respect to SM and the role of V_{ub} and f_B
- Comparison of sensitivity with LHC/Tevatron;





- Not clear at this point how much of this will go here, or directly in individual subsections

$B \to D^{(*)}\tau^+\nu$

- Useful to have a fairly extensive theory description; theorist input here?
- Hadronic tag analyses

BABAR refs:

PRD 79, 092002 (2009)

PRL 100, 021801 (2008) first BABAR result

Belle refs:

PRL 99, 191807 (2007)

arXiv:0910.4301 preliminary

- $B \to D^{(*)}\tau^+\nu$ results have only become available in the past few years and are still an active topic of study; "final" results expected to be available on time scale of book

Discussion

IV. Discussion, interpretation and future prospects

- Overall summary of Leptonic Decays and $B^+ \to D^{(*)}\tau^+\nu$ section
  - Interpretation in context of SM and possible new physics constraints
  - Avoid redundancy with material previously presented in subsections e.g. m_H vs $\tan\beta$; not clear at this point where discussion will fit best
  - Many analyses are statistics limited; useful to comment on possible limitations/issues for high luminosity B factories

Rare B decays

- General motivation for rare decay searches
  - typical "benchmark" scenarios (e.g. MSSM large tanβ), but not necessarily relevant to all modes; cite review articles and theory references, maybe also elsewhere in Book
- Methodology is also not common to these searches; mainly need to distinguish between "tagged" and "inclusive" searches

$\Rightarrow$ Both subsections anticipated to be short, with details relevant to specific modes discussed elsewhere

$B^0 \to l^+ l^-$ and related modes

III. $B^0 \to l^+ l^-$ (also $\tau^+\tau^-$ and $l^+l^-\gamma$)

- Generic theory motivation is straightforward, and can refer to EW/radiative penguin section if necessary. Probably need separate short theory motivations individual modes

BABAR refs:

PRD 77, 032007 (2008)	$B^0 \to l^+ l^-$	full dataset
PRD-RC 77, 011104 (2008)	$B^0 \to l^+ l^- \gamma$	full dataset
PRL 96, 241802 (2006)	$B^0 \to \tau^+\tau^-$	old result, but will not be updated

Belle refs:

PRD 68, 111101(R) (2003)	$B^0 \to l^+ l^-$	very old!

- $B^0 \to l^+ l^-$ is most stringent constraint, but new physics reach superseded by Tevatron $B_s^0 \to l^+ l^-$

Other rare modes

IV. $B^0 \to \gamma\gamma$
V. $B^0 \to$ invisible
VI. Lepton number/flavor violating modes

- $B^0 \to \gamma\gamma$ and $B^0 \to$ invisible sections short, with clear motivations and straightforward methodology

  BABAR refs:

  PRL 87, 241803 (2001) very old $B^0 \to \gamma\gamma$; update to full dataset expected soon

  PRL 93, 091802 (2004) $B^0 \to$ invisible with SL tag (update?)

  Belle refs:

  PRD 73, 051107 (2006) $B^0 \to \gamma\gamma$

  - $B^0 \to$ invisible study is in progress and expected to be ready in time for book

- LFV modes mostly published with related modes, with two exceptions:

  BABAR refs:

  PRD-RC 77, 091104 (2008) $B^0 \to l^+ \tau^-$ (essentially full dataset)

  PRL 99, 201801 (2007) $B^+ \to K^+ \tau^+ \mu^-$ (might be updated/extended)

Conclusions

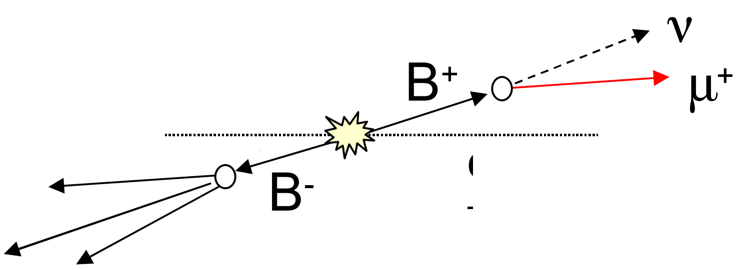
- Basic section(s) outline is available and notional content sketched out. Individual contributors not yet specifically identified, but not anticipated to be problematic
- Several key analysis topics are still lacking “final” BABAR and/or Belle results; many anticipated within the next six months (we'll see...)
- Some modest theory input might be useful for interpretation of new physics bounds and theory uncertainties

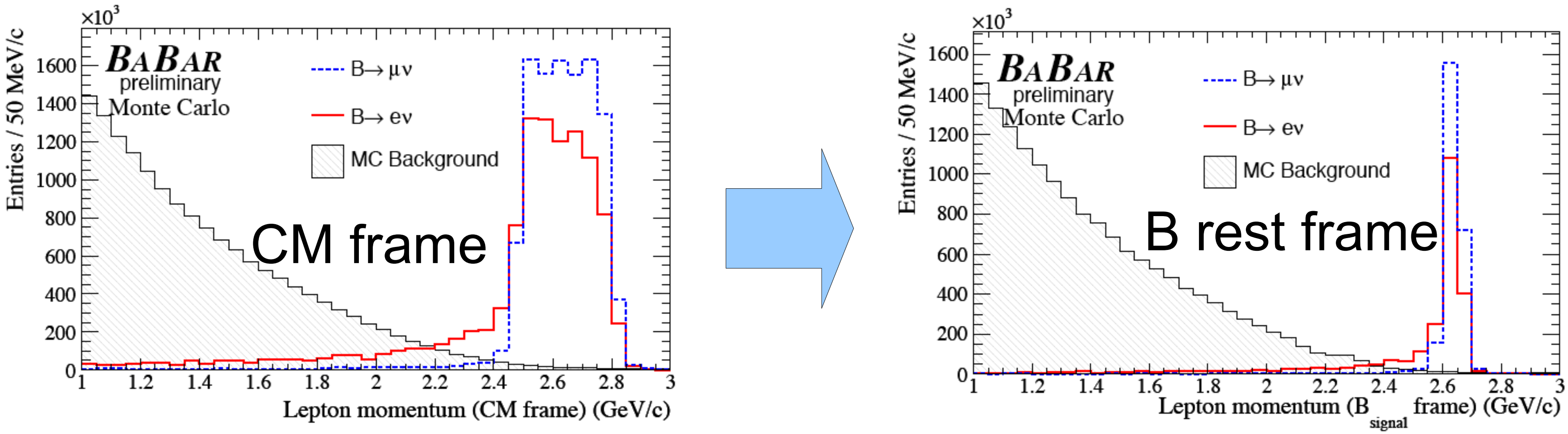
Backup slides

Tagged $B^+ \to l^+\nu$ $(l = e, \mu)$

Can use the hadronic B reconstruction method to search for other leptonic modes (e, μ) as well as τ mode

- only 1 neutrino, so reconstruction of tag B completely constrains event kinematics
- Signal B rest frame estimated from tag B 4-vector, permitting 2-body signal kinematics to be exploited





$B^+ \to l^+ \nu \gamma \quad (l = e, \mu)$

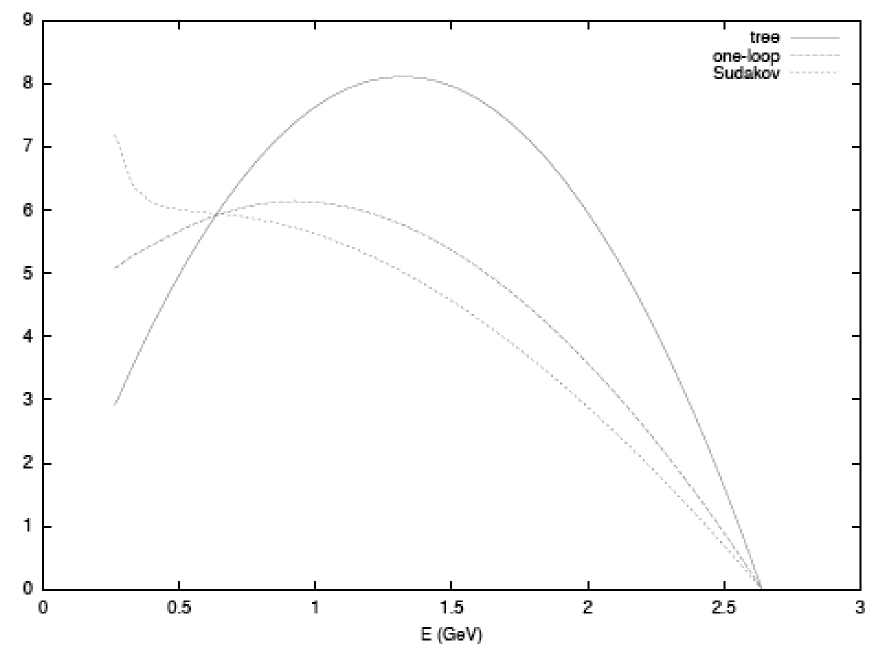
Presence of (hard) photon removes helicity suppression in purely leptonic decay modes, but adds factor of α and form factor uncertainties:

$$\frac{d\Gamma}{dE_\gamma} = \frac{\alpha G_F^2 |V_{ub}|^2}{48\pi^2} m_B^4 \left[f_A^2(E_\gamma) + f_V^2(E_\gamma)\right] x(1-x)^3$$

$B(B^+ \to l^+ \nu\gamma) \sim (1\text{-}5)\times 10^{-6}$ for all three modes

In practice, can extract λ_B which is related to B light cone wave function

$$\Gamma(B^+ \to l^+ \nu\gamma) = \alpha \frac{G_F^2 |V_{ub}|^2 m_B^5}{288\pi^2} f_B^2 \left(\frac{Q_u}{\lambda_B} - \frac{Q_b}{m_b}\right)^2$$



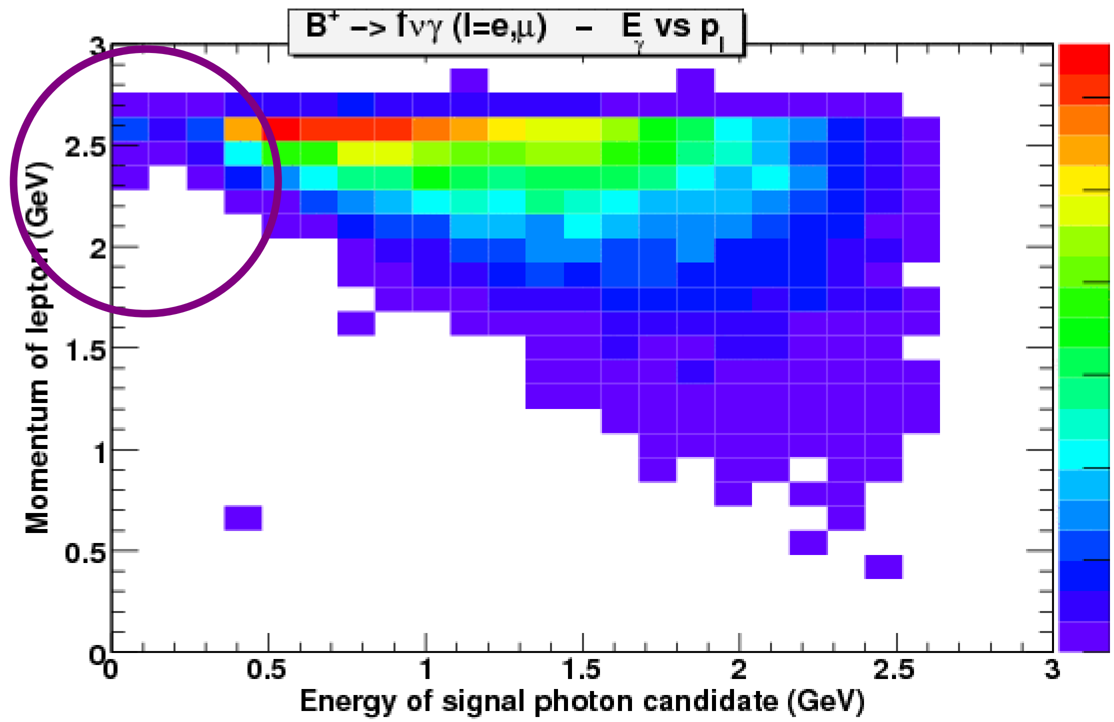
G. Korchemsky, D. Pirjol, T.-M. Yan
Phys. Rev. D61:114510, 2000. (hep-ph/9911427)

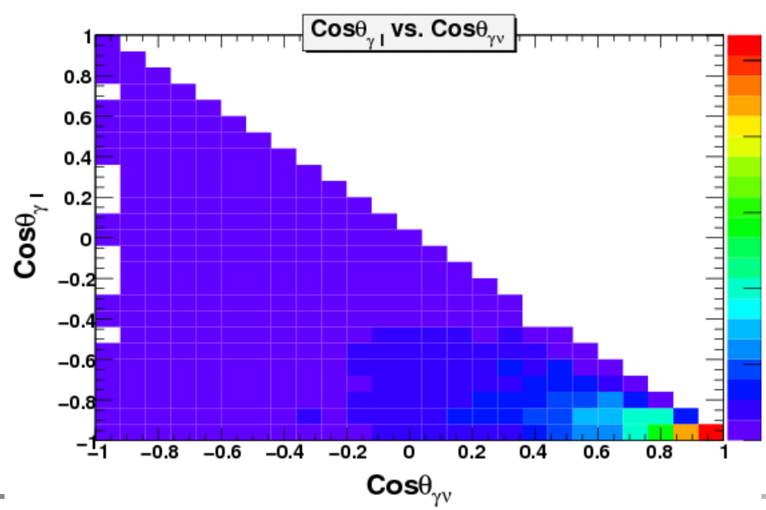
$B^+ \to l^+ \nu \gamma \quad (l = e, \mu)$

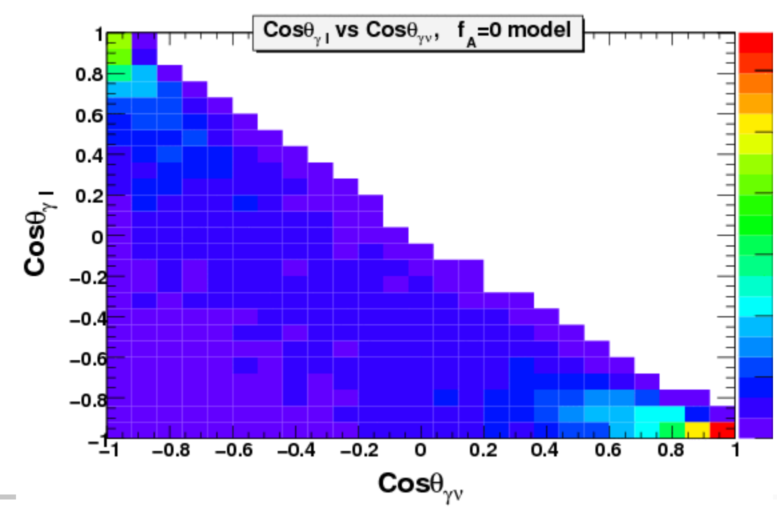
In limit of zero photon energy (actually, below a few 100 MeV) “signal” is helicity suppressed leptonic modes

- KPY model only valid down to ~few hundred MeV

- Difference in models mainly impacts angular distributions







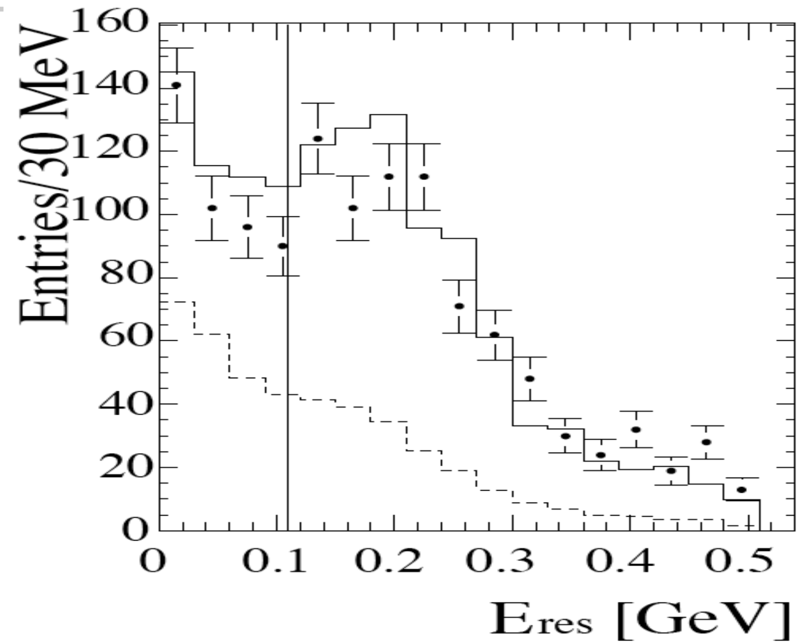
$B^0 \to \tau^+\tau^-$

Is unfortunately not a particularly good prospect...

- Only experimental results to date is from BABAR (PhD thesis of Chris Potter, Oregon):

$B(B^0 \to \tau^+\tau^-) < 3.2x10^{-3}$ (90%CL)
PRL 96 241802 (2006)

(SM expectation is ~$1x10^{-7}$)



- hadronic tagged analysis using neural net selection (Run 1-4 data)
  - with 254 background events observed in the signal region

The issue is irreducible background from $b \to c$ containing a K_L and (usually) one or more leptons

- Naïve scaling to $75ab^{-1}$ yields ~$2x10^{-4}$, but any real progress would require a very good detector and some additional experimental insight