B-decays with τ-leptons in the final state

Silke Nelson, SLAC for the BABAR Collaboration

Fermilab Wine and Cheese Seminar

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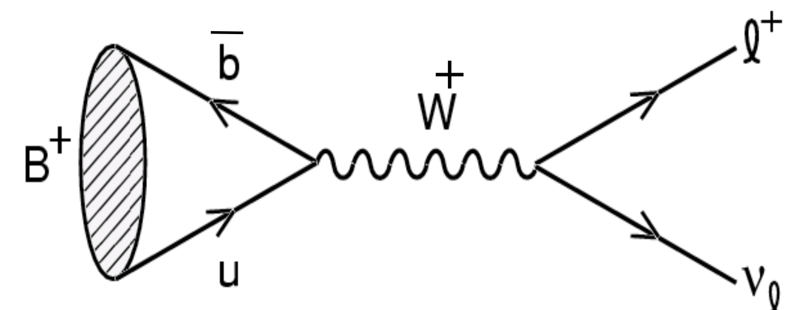
Outline

- Introduction
  - Motivation
  - Experiment and Dataset
  - Methods
- Measurements
  - "Rare" decays: $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$
  - Forbidden decays: $B \to \tau l$ and $B \to K\tau\mu$
- Summary and Outlook

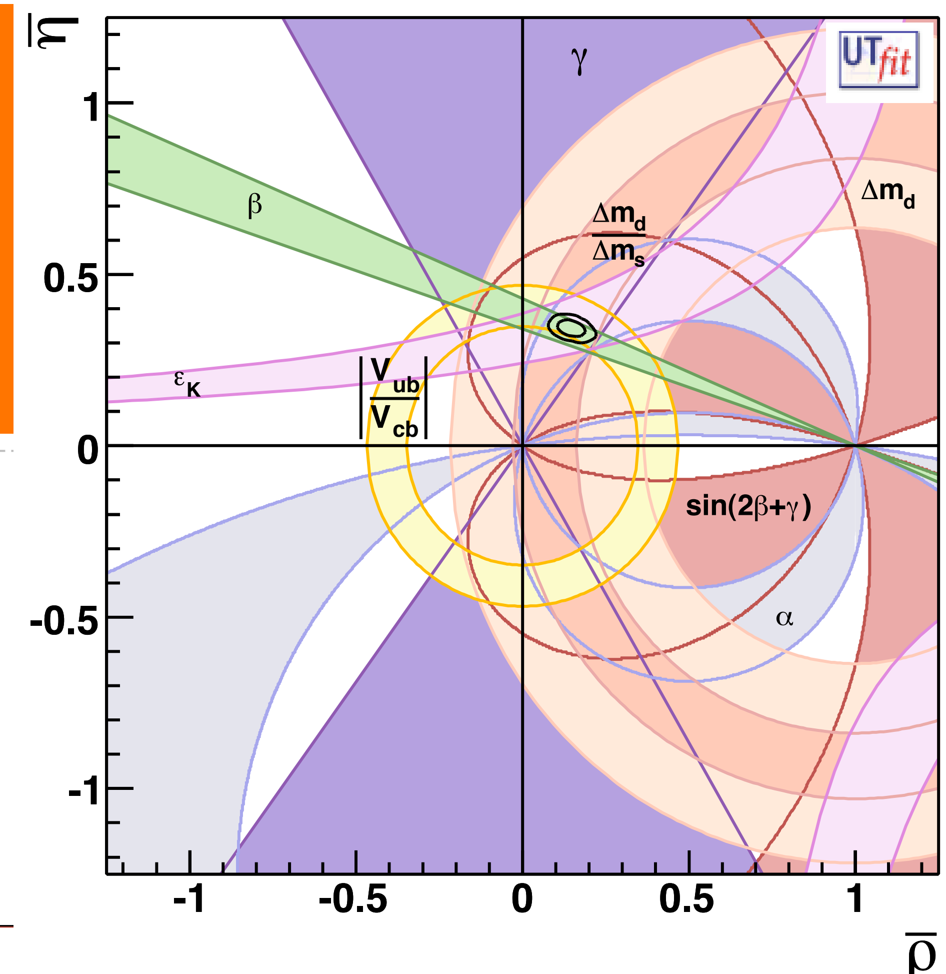
Motivation - Why Leptons?

- **+** relatively little hadronic uncertainties (contained in decay constant f_B)
- **-** for pure leptonic decay: helicity suppression (m_l^2)
- **+** have "easy" experimental signature (Particle IDentification)
- **-** have neutrino(s) in final state

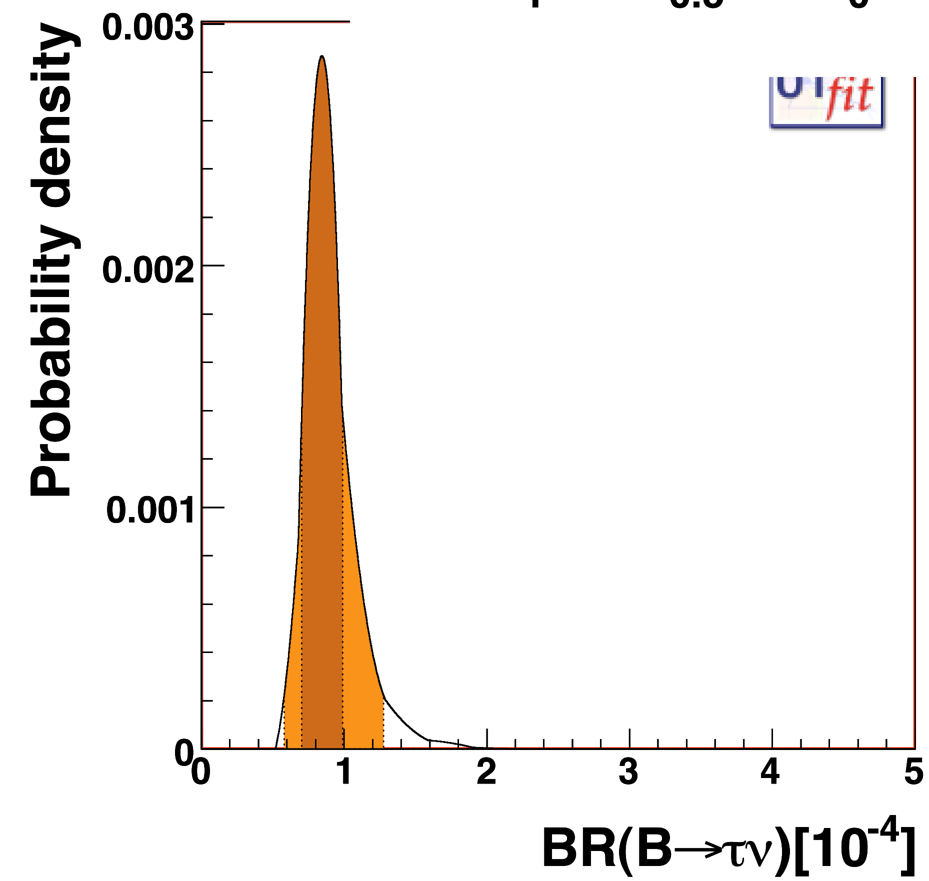


$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Motivation - Why Leptons?

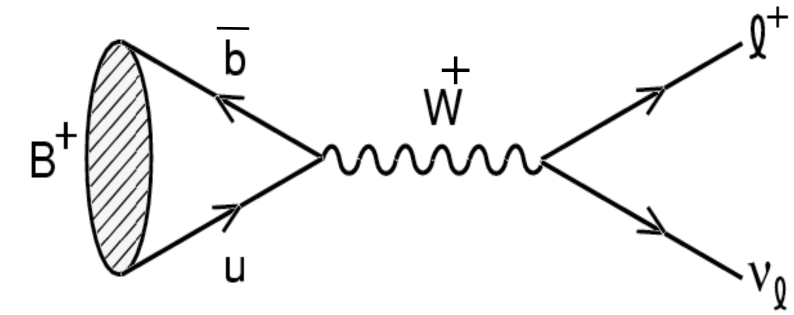


- independent constraint in $\overline{\rho},\overline{\eta}$ plane
- other measurements deliver a prediction
  - use experimental values for Δm_s and Δm_d together with lattice value for $f_B\sqrt{B_{Bd}}$
    - BR ($B\rightarrow\tau\nu$) = (0.85 ± 0.14) x 10^{-4}
- compare to lattice calculation for f_B



Motivation - Why Taus?

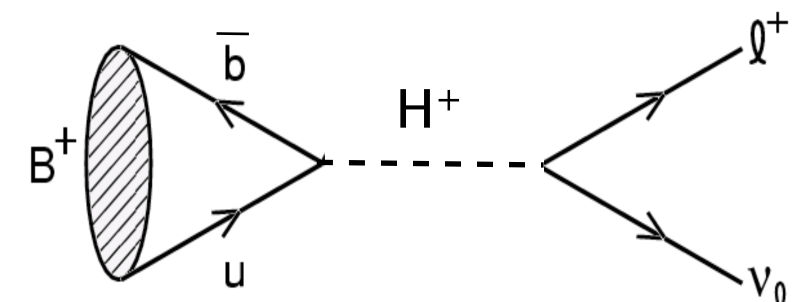
- + helicity suppression in leptonic decays relieved for more massive τ - relatively large BF



- - have (more) neutrinos in final state

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- + stronger coupling to Higgs-like particles
  - look at type II 2HDM: simplest model with extended Higgs sector
    - similar to Higgs sector in MSSM



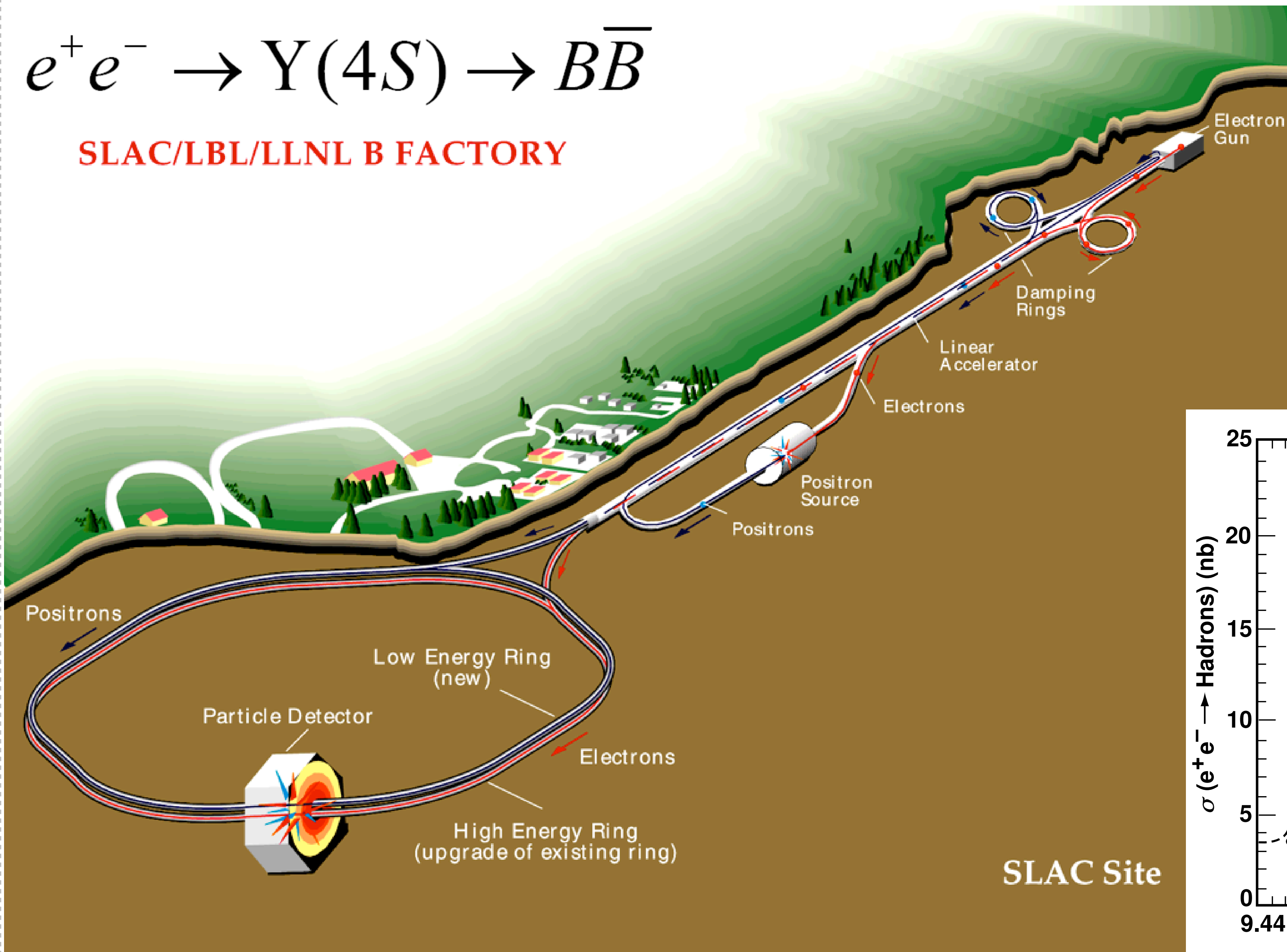
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

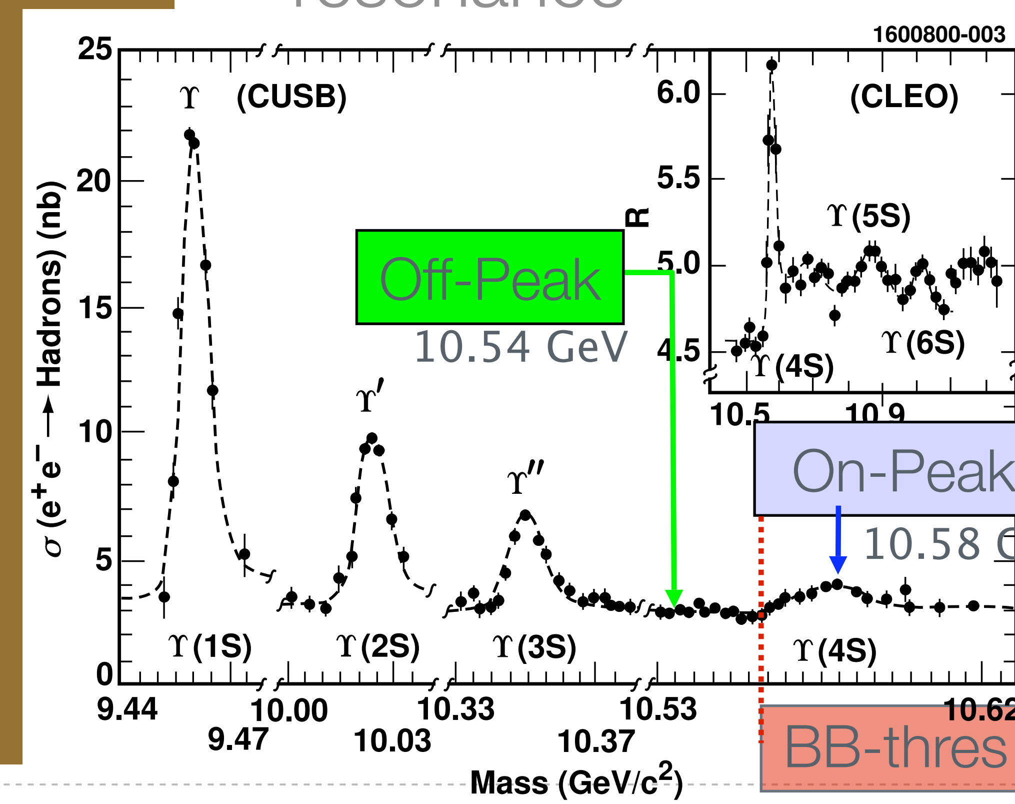
W.-S. Hou, Phys. Rev. D. Brief Report 48 (1993) 2342

Experimental Setup: PEP II

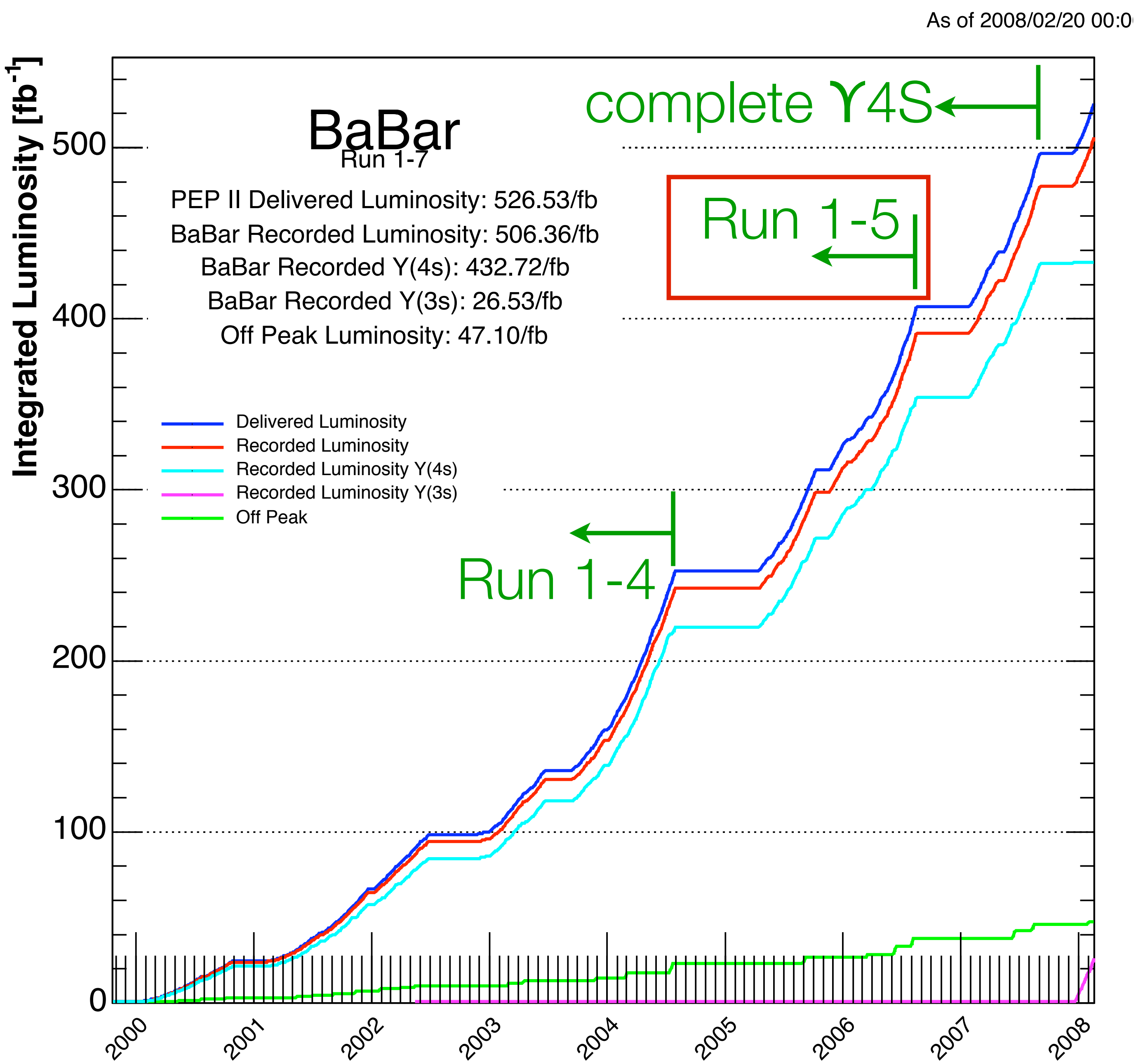
$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$$



- asymmetric B-factory
  - also a charm and $\tau\tau$ factory
- now running at the Υ(3S) resonance

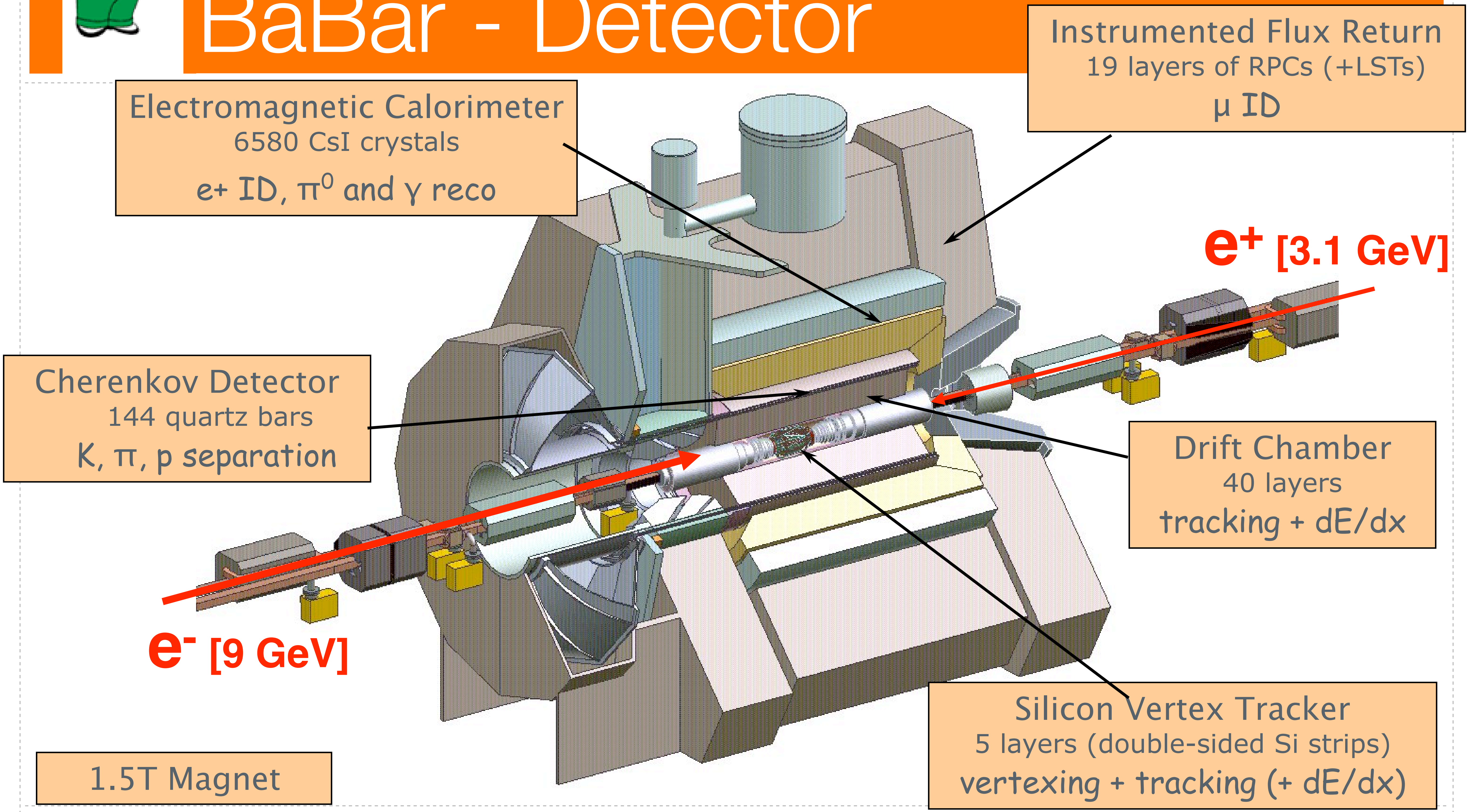


Experimental Setup: Dataset



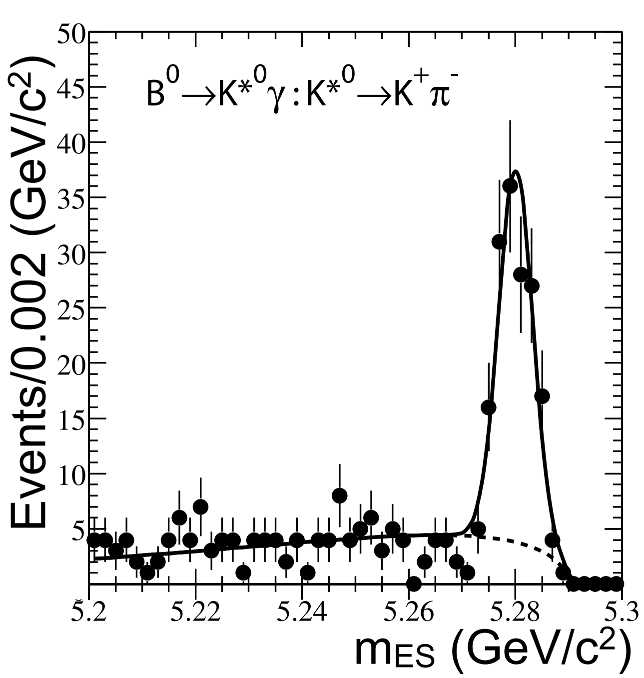
- collected 433 fb^{-1} at the Υ(4S) resonance
- complete Υ(4S) dataset in hand
  - most analyses presented here use ~340 fb^{-1}: ~380 M B-pairs (Run 1-5)
  - $B \to D^{(*)} \tau \nu$ uses 232 M BB-pairs

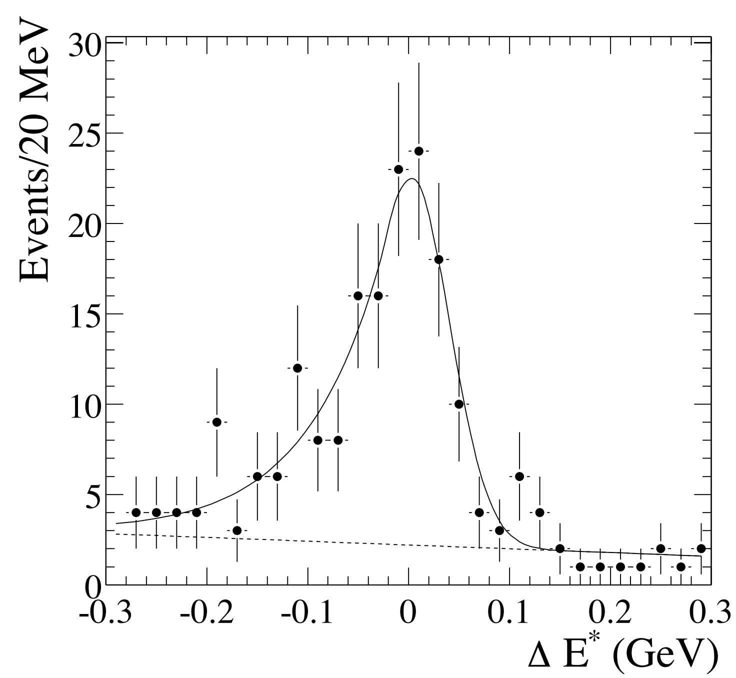
Experimental Setup: BaBar - Detector

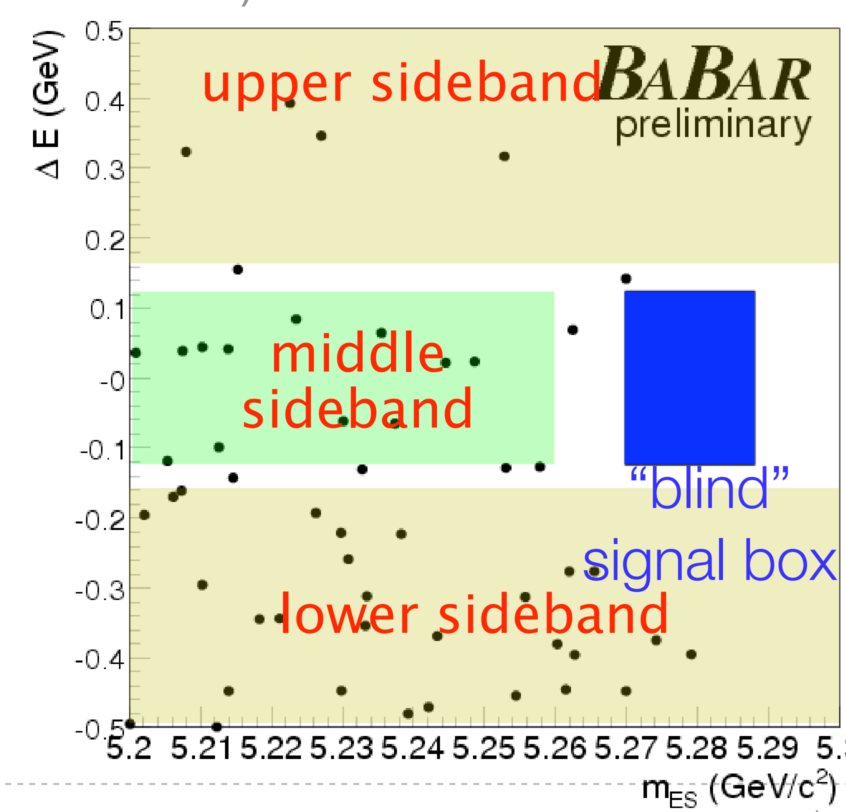


Experimental Methods

- e^+e^--collider → beam energy (and thus the center-of-mass) is known very well
- calculate two (almost) independent variables: energy difference $\Delta E = E_B - E^*_{beam}$ and effective mass $m_{ES} = \sqrt{(E^*_{beam})^2 - p_B^2}$
- define signal-rich region (signal box) and background rich sidebands for cross checks
- keep signal box blind until analysis cuts (and systematic uncertainties) are determined

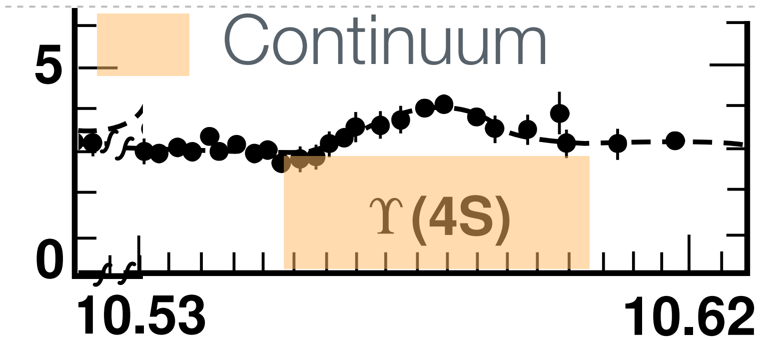




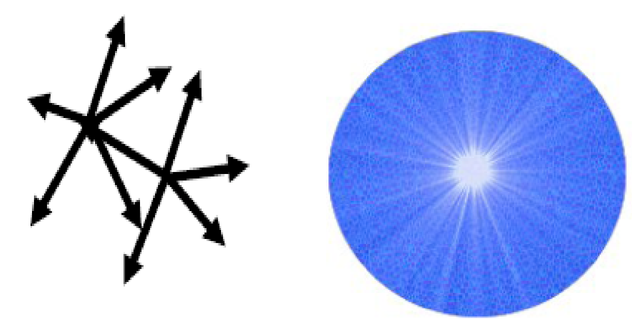


Experimental Methods (II)

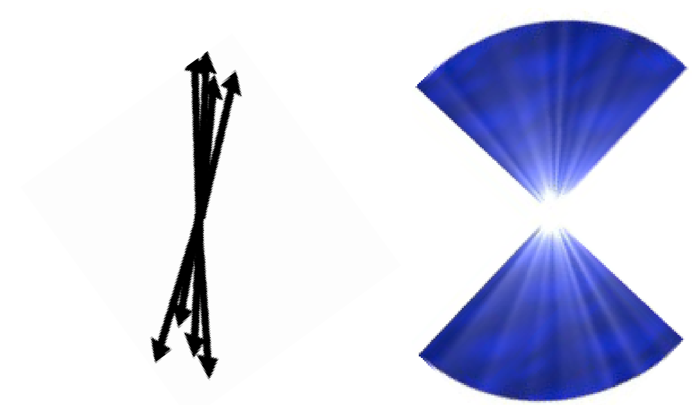
- substantial fraction of events are non-BB events
- light quark events more "jetty"
  - use event shape variables as thrust angles, Fox-Wolfram moments either as cut variables or input to Fisher-discriminant or Neural Net

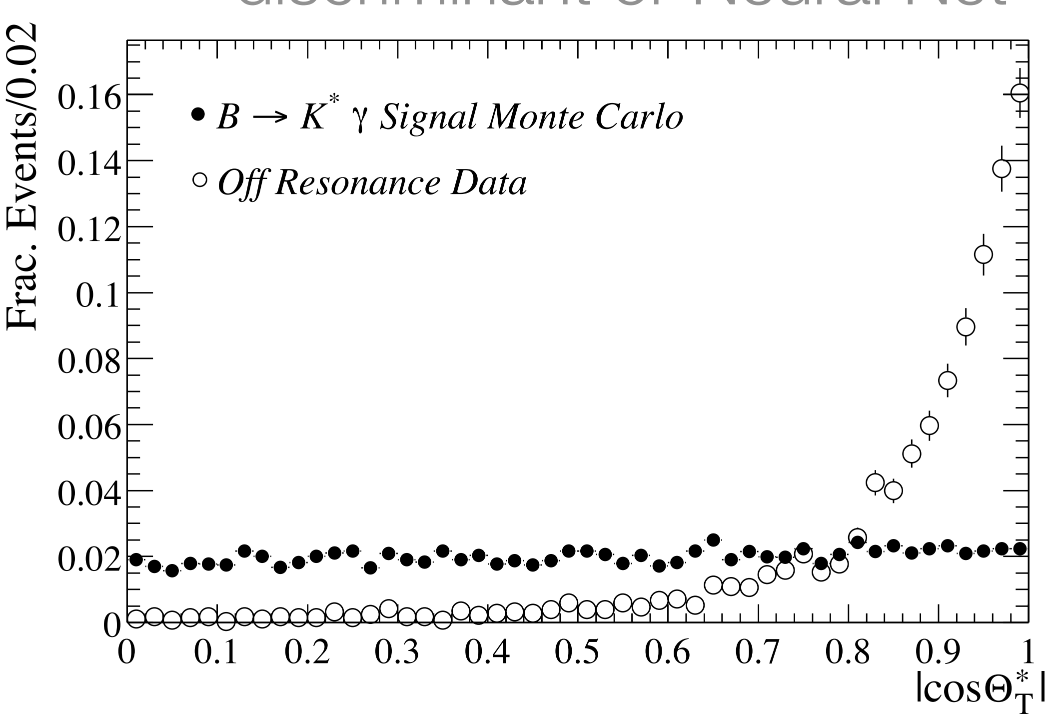


BB - event



u,d,s,c,τ event

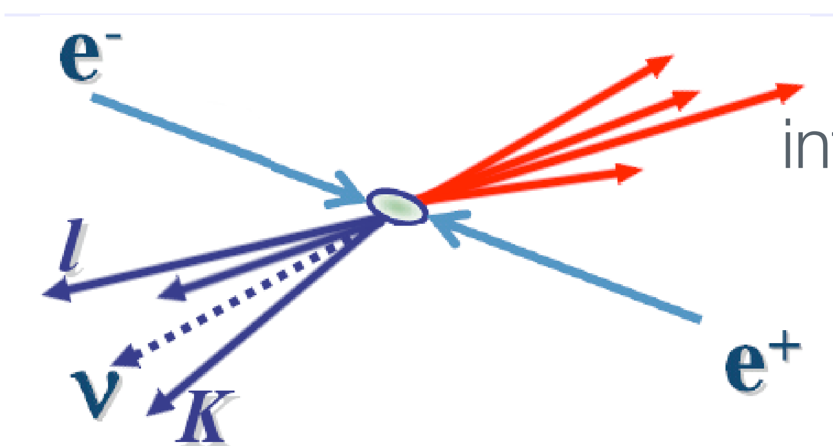




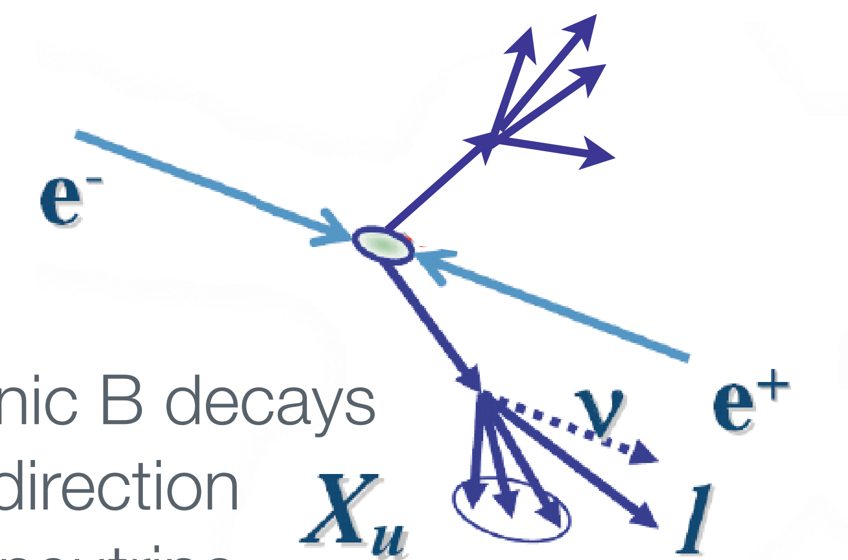
angle between thrust axis of B and Rest-Of-Event

Experimental Methods (III)

- neutrinos escape undetected
  - use missing energy vector
    - includes all missing particles (decays of both B-mesons, acceptance effects)



charm events:
infer direction from
topology

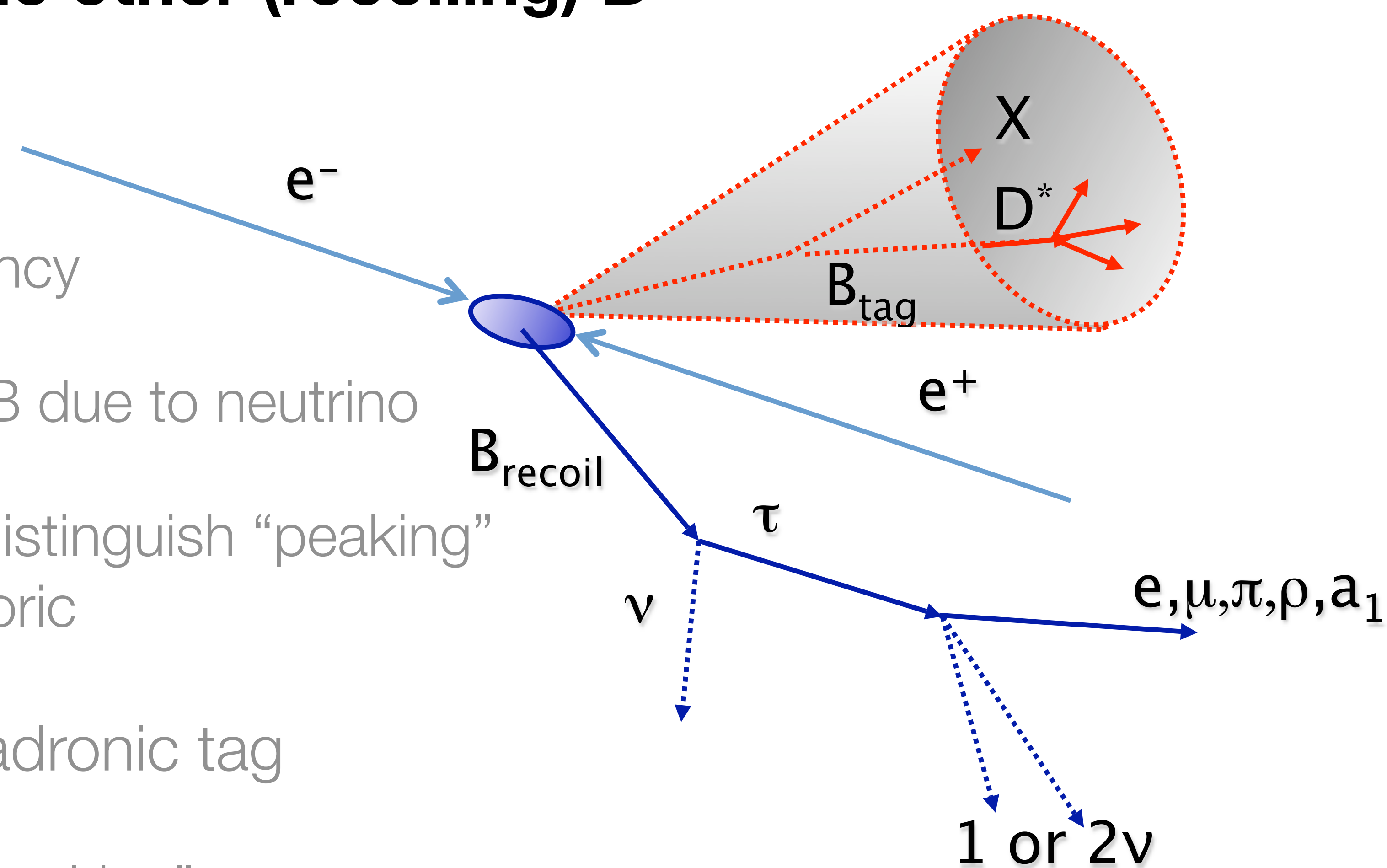


semileptonic B decays
infer direction
from neutrino
mass

- B-decays with > 1 neutrino: neither works....

Experimental Methods (IV): "Tagging"

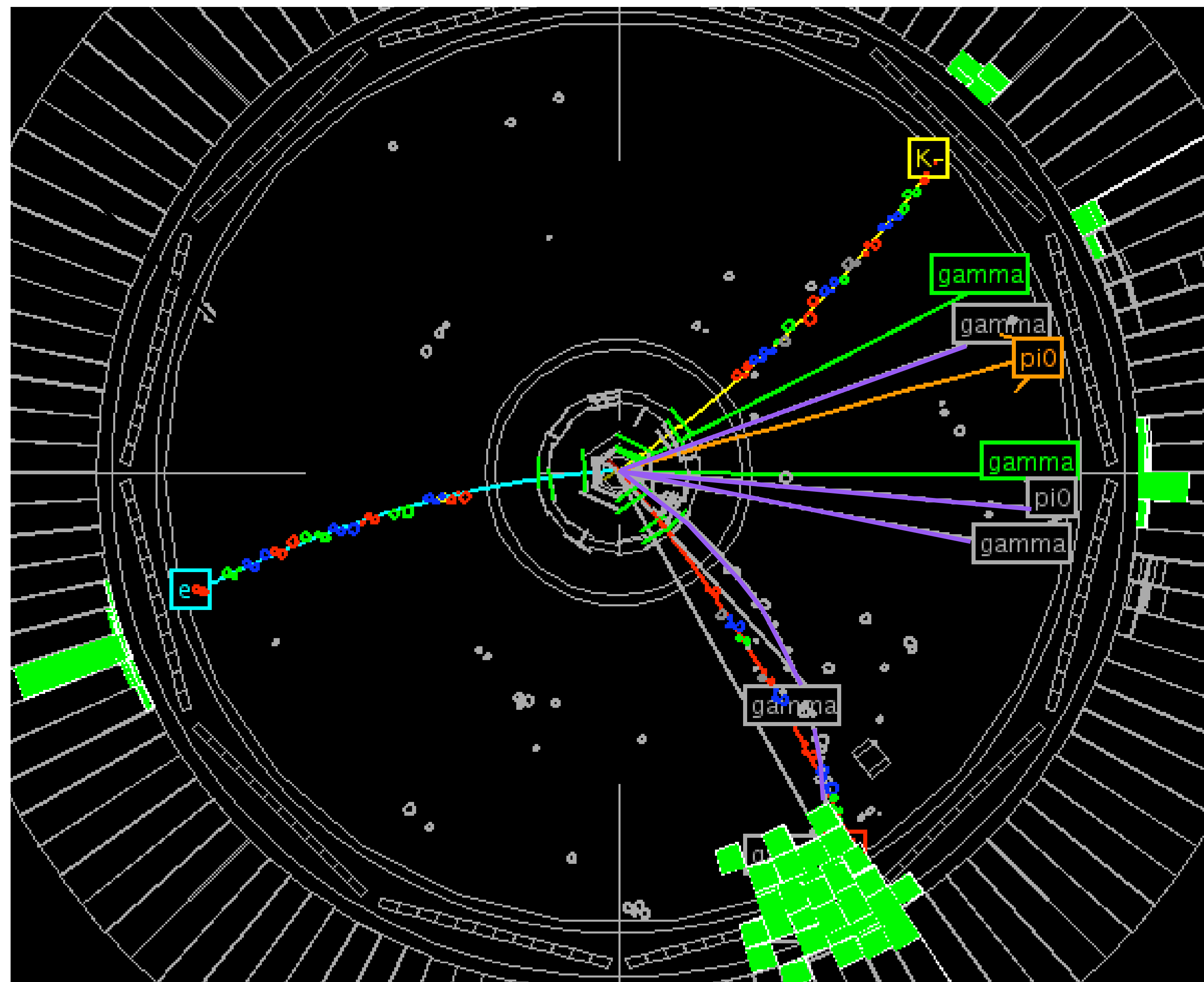
- **reconstruct one B: study the other (recoiling) B**
  - $D^{(*)}l\nu$: semileptonic tag
    - higher reconstruction efficiency
    - less information about Tag-B due to neutrino
    - use D-mass as variable to distinguish "peaking" background from combinatoric
  - $D^{(*)}(n\pi^{\pm}\ mK^{\pm}\ rK_S^0\ q\pi^0)$: fully hadronic tag
    - use ΔE and m_{ES} to select "peaking" events
    - ~ 1/3 of semileptonic tagging efficiency



Measurements

Measurements: $B \rightarrow \tau\nu$

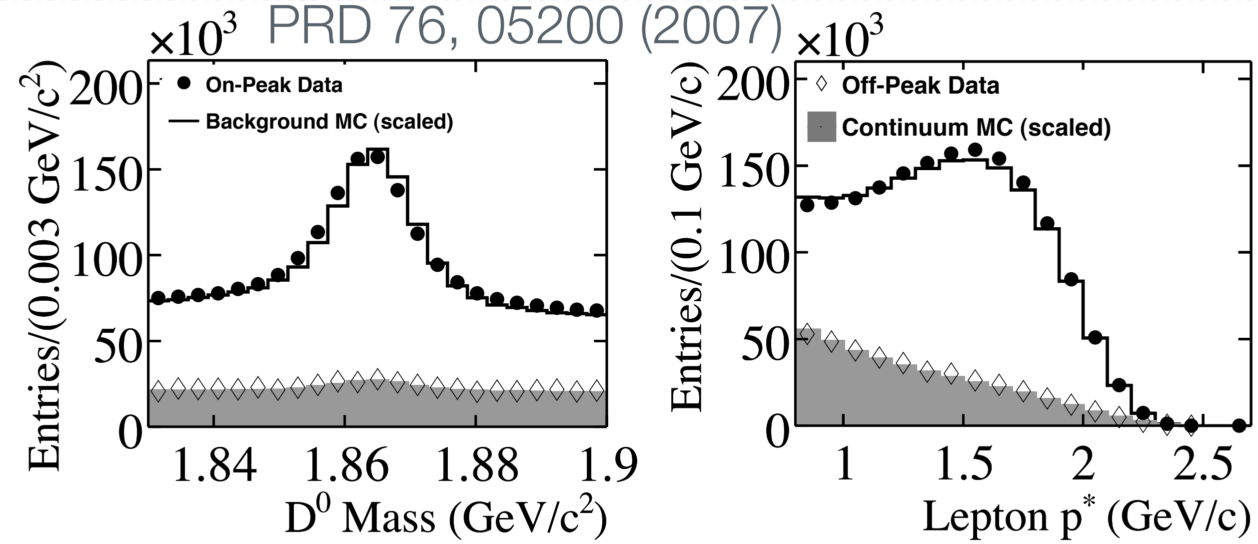
- signal MC event
  - with semileptonic Tag-B
    - $B \rightarrow D^{*} e\nu$, $D^{*} \rightarrow D^{0}\pi^{0}$, $D^{0} \rightarrow K\pi$
  - τ decays into $\pi\pi^{0}$
    - require well-identified objects as daughters
  - characterize event by E_{extra}: (energy not assigned to Tag-B or the τ-daughters)



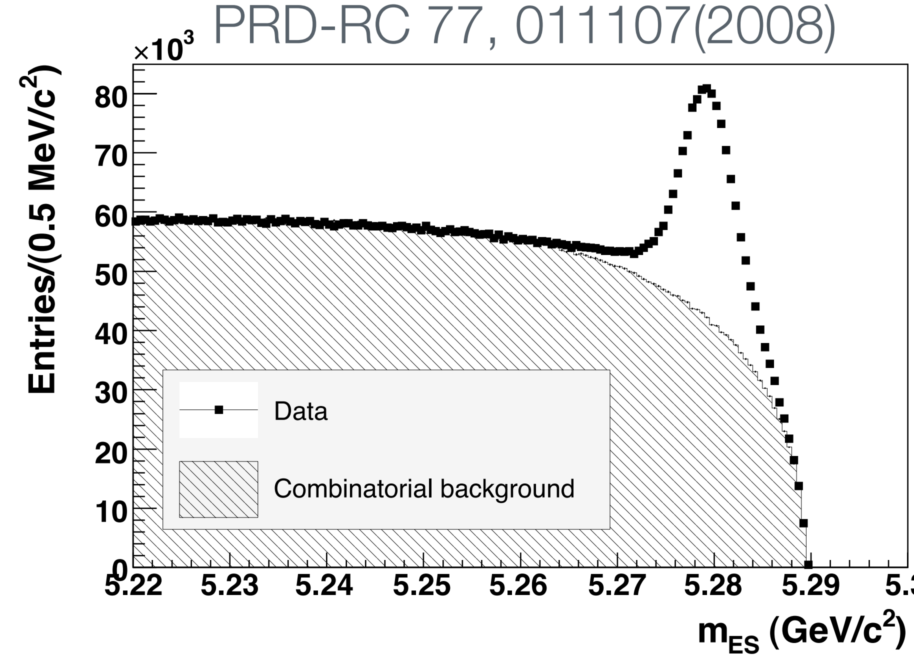
B→τν: Tagging (II)

- use D(*)X decays
  - X = lν: semileptonic tag
    - higher reconstruction efficiency
    - less information about Tag-D due to neutrino
    - use D-mass (and lepton momentum) to distinguish “peaking” background from combinatoric
  - X = $n\pi^{\pm}\, mK^{\pm}\, rK_S^0\, q\pi^0$: fully hadronic tag
    - use ΔE and m_{ES} to select “peaking” events
    - ~ 1/3 of semileptonic tagging efficiency

PRD 76, 05200 (2007)



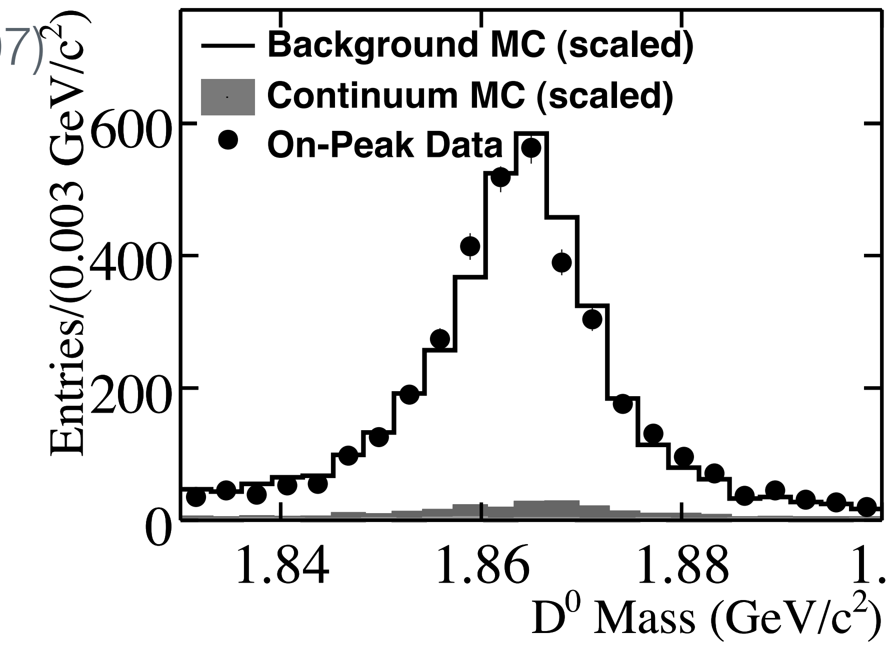
PRD-RC 77, 011107(2008)



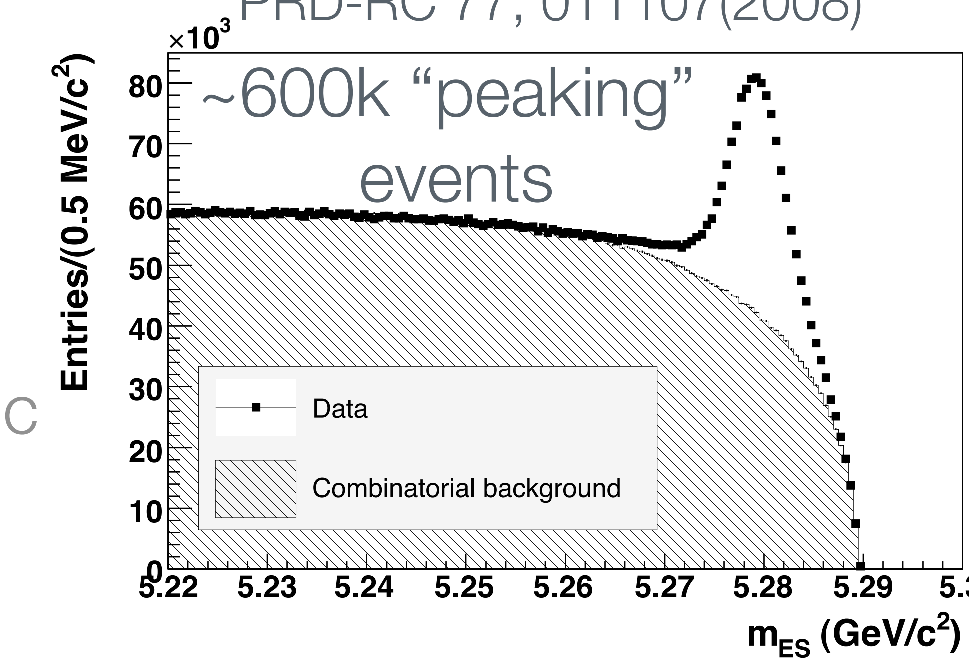
B→τν: Tagging (III): Efficiency

- $D^{(*)}l\nu$: semileptonic tag
  - efficiency is (6.64±0.03)x10^{-3} (signal MC)
  - study double tagged (2 non-overlapping tags) events in data and MC to estimate efficiency correction
    - systematic from statistical error
- hadronic tag
  - count peaking event in m_{ES} by subtracting combinatorial events using a template from MC
  - correct for tagging efficiency difference of generic B-decay and signal events
  - systematic estimated by changing template

PRD 76, 05200 (2007)

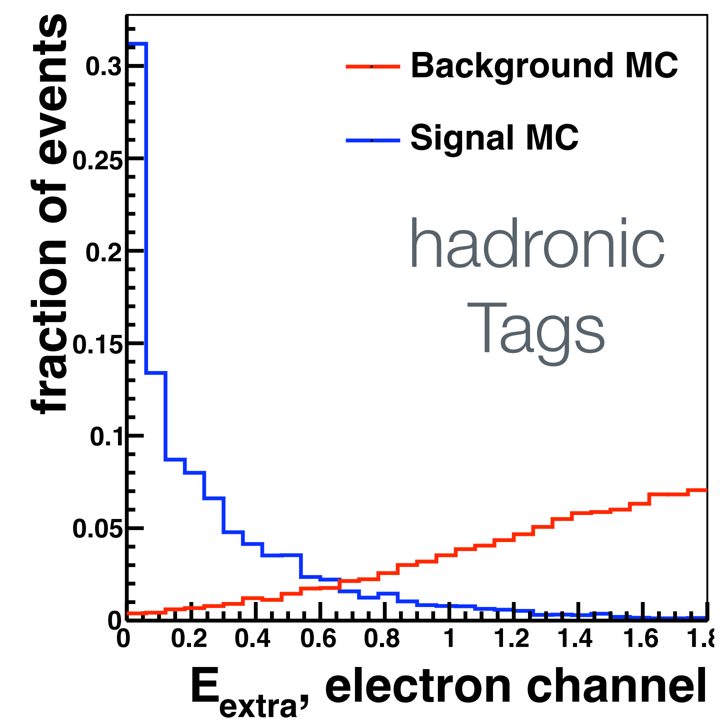


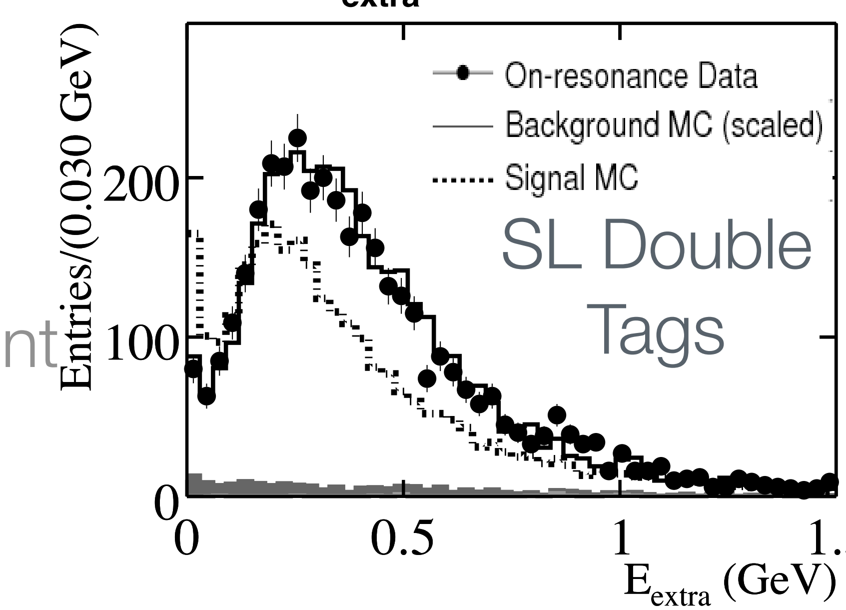
PRD-RC 77, 011107(2008)



B→τν: E_{extra}

- the summed energy of "extra" particles (E_{extra}) is the most powerful variable to distinguish signal from background
- modeling needs to describe clusters from background events, radiated photons and "split-offs"
  - background event from data taken by random triggers are superimposed on MC events
  - in particular "split-offs" are not well described
  - use event with two tags to check data-MC agreement
    - as in signal, all particles should be included in Tag-B and Signal-B



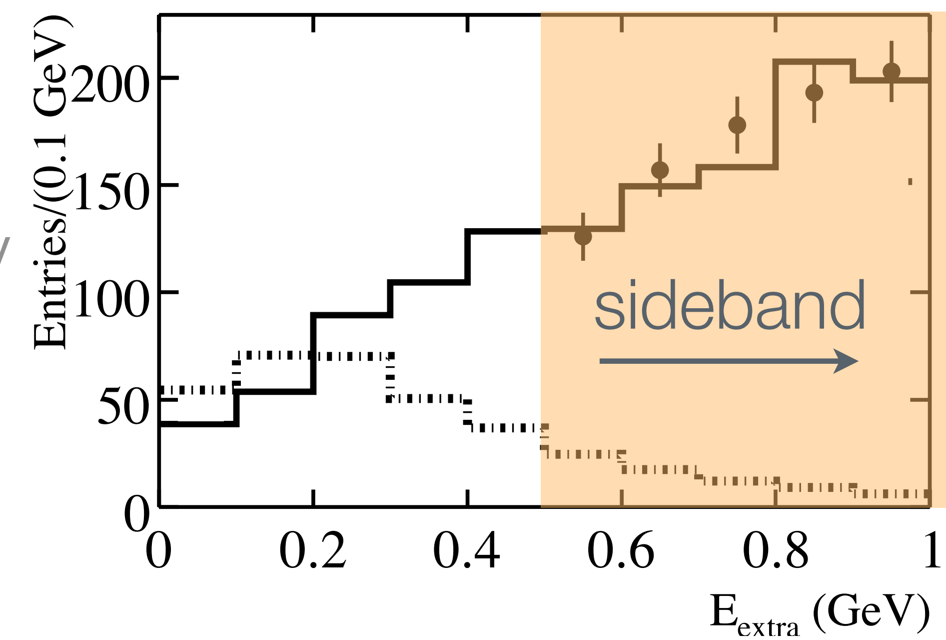


$B \to \tau\nu$: Event Selection

- require a good Tag-B and use the good tracks and photons in the recoil to separate events into 4 tau decay classes: e, μ, π, ρ
  - the a1 mode does not contribute to significance due to its large background
- simultaneously optimize cuts on:
  - E_{extra}
  - little presence of "extra" particles (K_L^0, tracks, π^0)
  - the momentum of the tau-daughter
  - continuum rejection
    - for the semileptonic tag, take extra care of $\tau\tau$ events: if they enter final sample, they peak in E_{extra}!
- selection efficiencies of ~1-5% in each channel, total of 10(had)-13(SL)%
  - this is after tagging and signal-B reconstruction

B→τν: Background Prediction Semileptonic Tag

- use sidebands (SB) in data
- scale the amount of data in the E_{extra} SB region by the ratio of MC events in the SB and signal region: $$N_{exp,sig} = N_{data,sb} \times \frac{N_{MC,sig}}{N_{MC,sb}}$$
  - cross-check by using the m(D^0)-SB region in the E_{extra} signal region (SR) scaled to the m(D^0) SR (comb. background) $$N_{exp} = N^{data}_{comb} + (N^{MC}_{total} - N^{MC}_{comb})$$

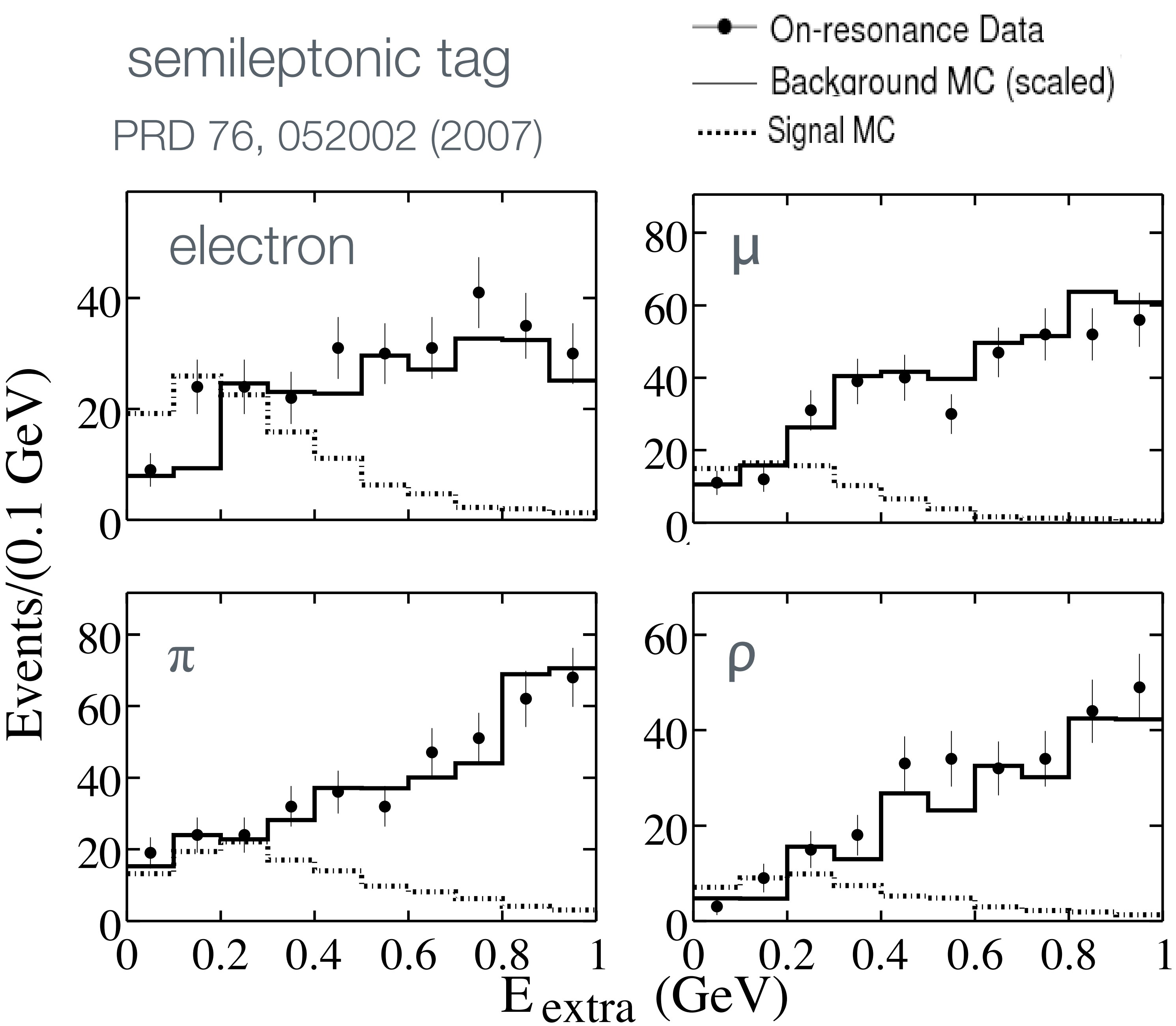


signal mode	Background Prediction e^+	μ^+	π^+	$\pi^+\pi^0$
E_{extra} sideband	44.3±5.2	39.8±4.4	120.3±10.2	17.3±3.3
D^0 sideband	44.2±6.4	42.8±6.0	113.4±11.6	16.3±4.5

$B \to \tau\nu$: E_{extra} in Data and MC

semileptonic tag

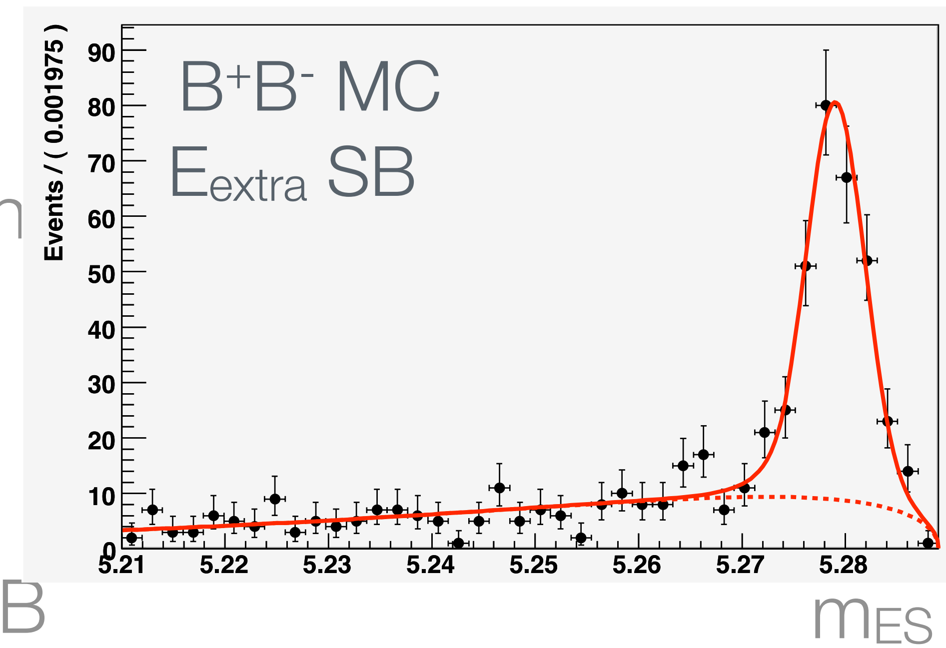
PRD 76, 052002 (2007)



τ decay mode	Expected background events	Observed events in on-resonance data
$\tau^+ \to e^+\nu\bar{\nu}$	44.3 ± 5.2	59
$\tau^+ \to \mu^+\nu\bar{\nu}$	39.8 ± 4.4	43
$\tau^+ \to \pi^+\bar{\nu}$	120.3 ± 10.2	125
$\tau^+ \to \pi^+\pi^0\bar{\nu}$	17.3 ± 3.3	18
All modes	221.7 ± 12.7	245

B→τν: Background Prediction Hadronic tag

- use sidebands (SB) in data
- use m_{ES} fits in the E_{extra} SB and E_{extra} signal region at final selection stage



$$N_{exp,sig} = \boxed{N_{pk}^{low,MC}} \times \frac{N_{pk}^{high,data}}{N_{pk}^{high,MC}} + \boxed{n_{comb}}$$

- cross-check by also using m_{ES} fits in the E_{extra} SB at Preselection stage

$$\boxed{n_{comb}^{sig}} = n_{comb}^{sig,presel} \times \frac{N_{comb}^{high,data}}{N_{comb}^{high,data,presel}}$$

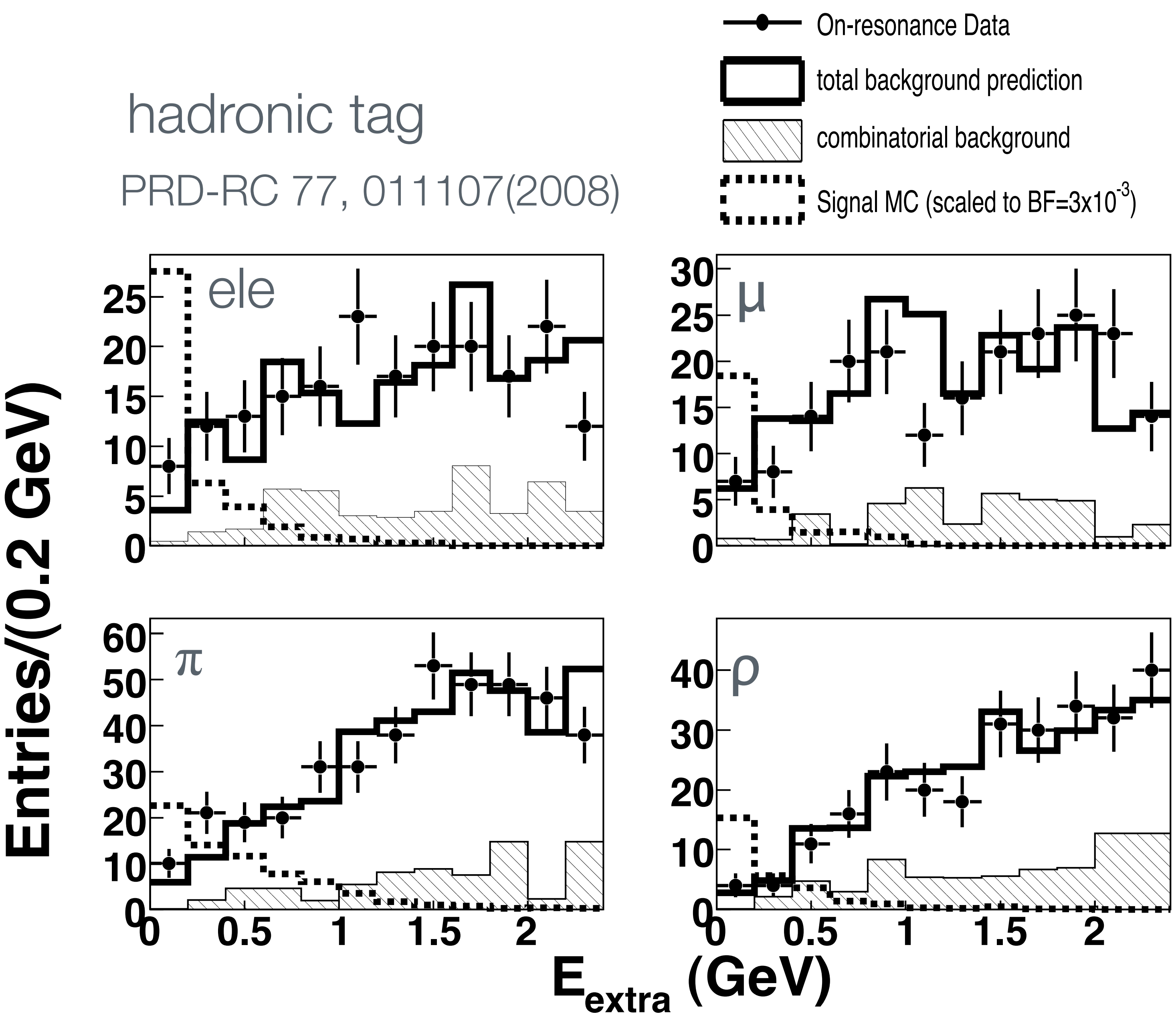
$$\boxed{N_{pk}^{low,MC}} = N_{tot}^{low,MC} - n_{comb}^{MC,presel} \times \frac{N_{comb}^{high,MC}}{N_{comb}^{high,MC,presel}}$$

  - thus avoiding fits in the E_{extra} SR (low statistics!)
- average predictions, use difference as systematic

B→τν: E_{extra} in Data and MC

hadronic tag

PRD-RC 77, 011107(2008)



τ decay mode	Expected background	Observed
$\tau^+ \to e^+\nu\overline{\nu}$	1.47 ± 1.37	4
$\tau^+ \to \mu^+\nu\overline{\nu}$	1.78 ± 0.97	5
$\tau^+ \to \pi^+\overline{\nu}$	6.79 ± 2.11	10
$\tau^+ \to \pi^+\pi^0\overline{\nu}$	4.23 ± 1.39	5
All modes	14.27 ± 3.03	24

B→τν: Systematics

- tagging efficiency (correction)
- E_{extra} modeling
- K_L^0 veto efficiency: use double tag sample
- tracking Efficiency
  - use ττ-events of a 1-3 topology
- Particle Identification
  - correction as functions of particle momentum and angle, determined in clean samples
- π^0 efficiency
  - use τ-decays: compare rates of $\pi^\pm$ to $\pi^\pm\pi^0$ decays

SL Tag

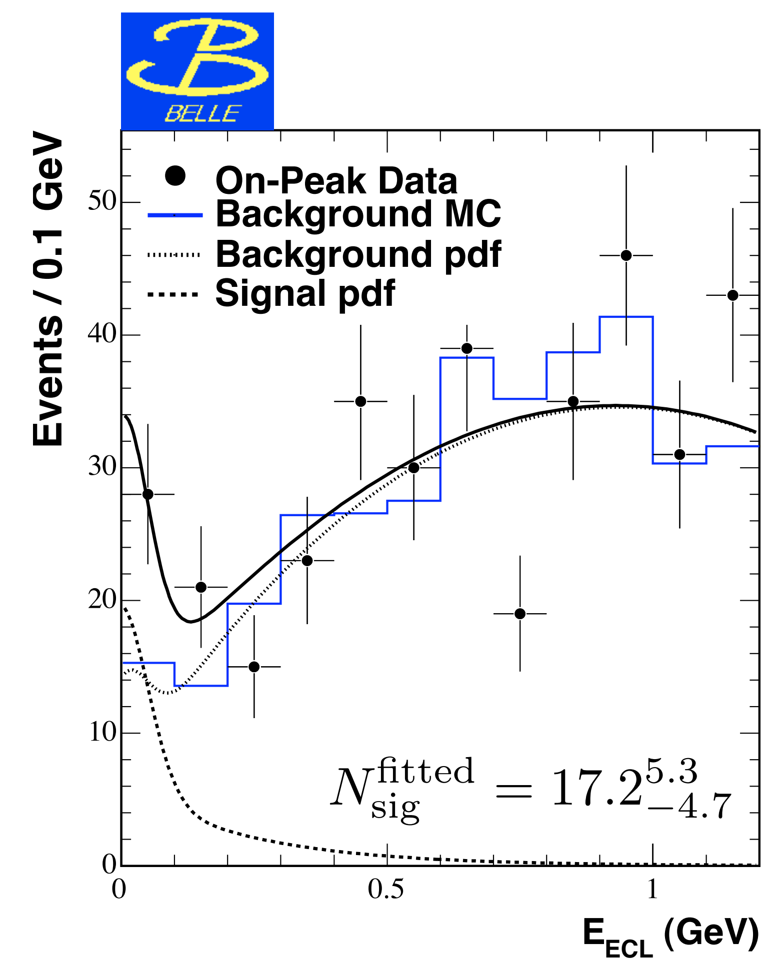
τ decay mode	$e^+\nu\bar{\nu}$	$\mu^+\nu\bar{\nu}$	$\pi^+\bar{\nu}$	$\pi^+\pi^0\bar{\nu}$
Tracking	0.5	0.5	0.5	0.5
Particle Identification	2.5	3.1	0.8	1.5
π^0	–	–	–	2.9
EMC K_L^0	–	–	3.8	–
IFR K_L^0	3.3			
$E_{\rm extra}$	3.4			
signal B	5.5			
tag B	3.6			
$N_{B\bar{B}}$	1.1			
Total	6.6			
Correction Factor	0.951	0.868	0.964	0.939

Had Tag

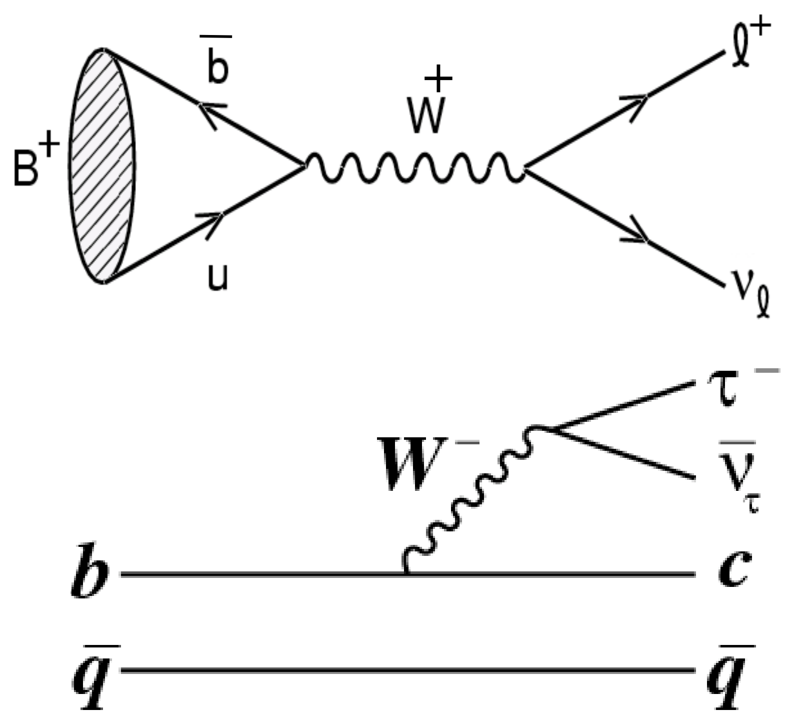
Source of systematics	e^+	μ^+	π^+	$\pi^+\pi^0$	Total
MC statistics	3.1	0.6	1.5	2.6	4.3
Particle Identification	1.5	1.3	0.2	0.2	2.0
π^0	–	–	–	1.4	1.4
Tracking	3.7	0.4	0.1	1.6	5.8
$E_{\rm extra}$	4.7	0.6	0.9	2.6	8.8
Signal B					11.6
Tag B					3
Total					12

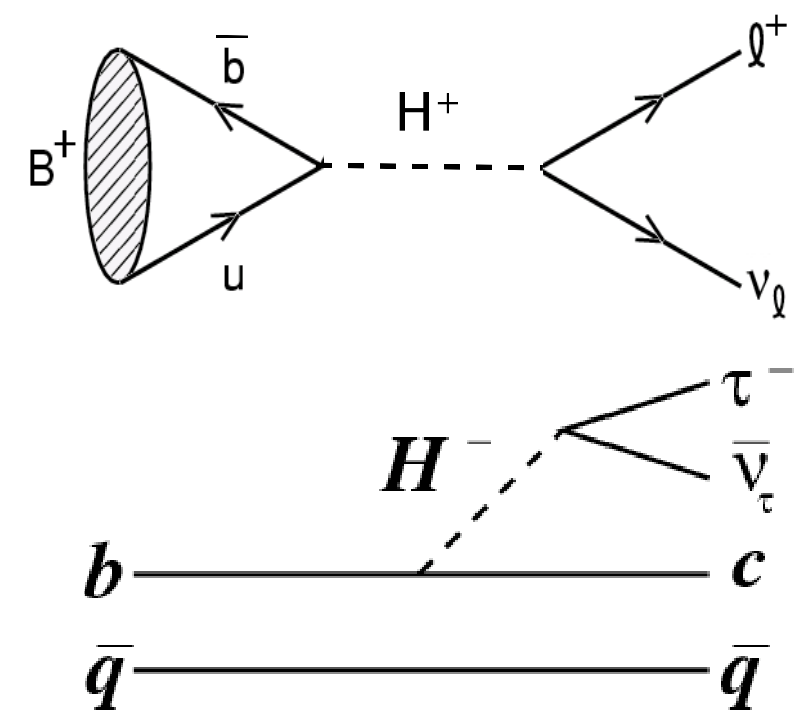
B→τν: Experimental Status

- BaBar
  - semileptonic tag, 383 M BB, PRD-RC 77, 011107 (2008):
    $(0.9 \pm 0.6 \pm 0.1) \times 10^{-4}$
  - hadronic tag, 383 M BB, PRD 76, 05200 (2007):
    $(1.8^{+1.0}_{-0.9} \pm 0.3) \times 10^{-4}$
  - combined
    $(1.2 \pm 0.4_{stat} \pm 0.3_{bkg} \pm 0.2_{syst}) \times 10^{-4}$
- Belle
  - hadronic tag, 447 M BB, PRL 97, 251802 (2006):
    $(1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$
- World Average (HFAG, August 2007)
  $(1.41^{+0.43}_{-0.42}) \times 10^{-4}$



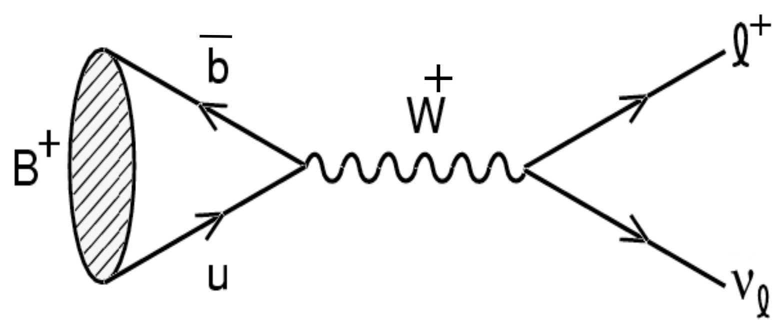
$B \to D^{(*)}\tau\nu$: Motivation

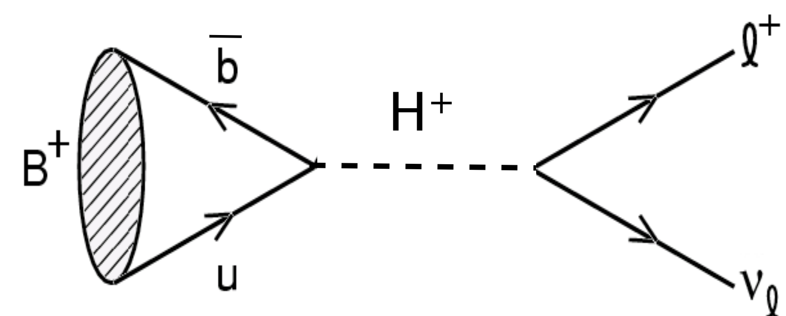


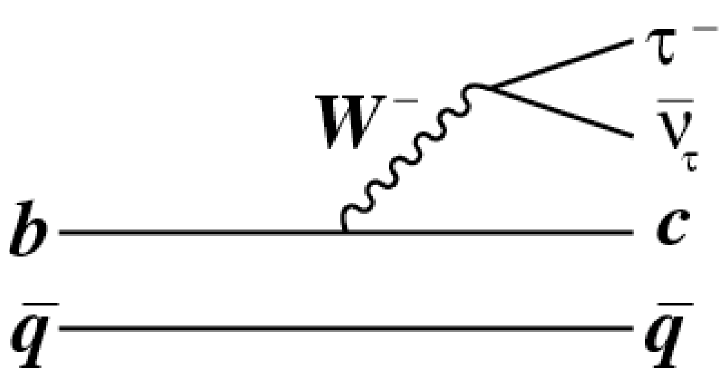


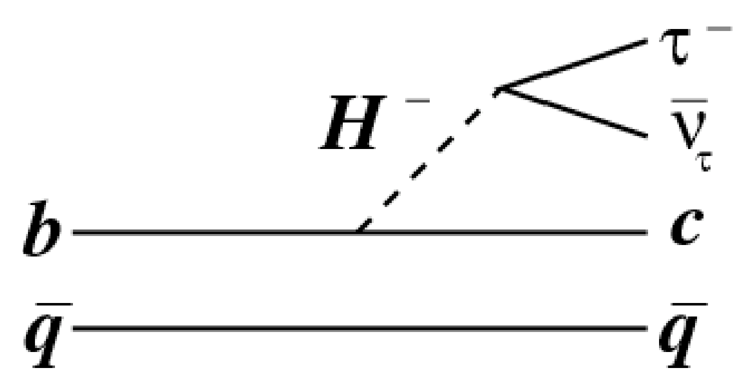
- from $B \to \tau\nu$ to $B \to D^{(*)}\tau\nu$
  - go from annihilation to exchange diagram (charged + neutral channels)
  - go from V_{ub} to V_{cb}

B→D$^{(*)}$τν: Motivation

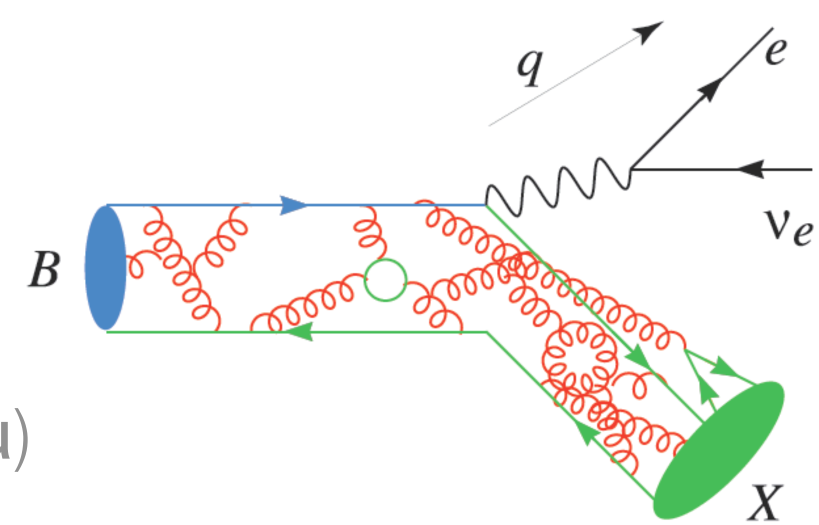


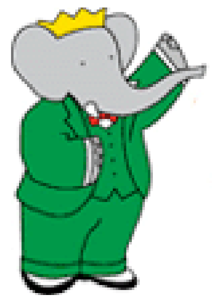






- add a spectator quark
  - complicates theoretical prediction
  - but can look at ratio B→D$^{(*)}$τν/B→D$^{(*)}$lν (l=e,μ)

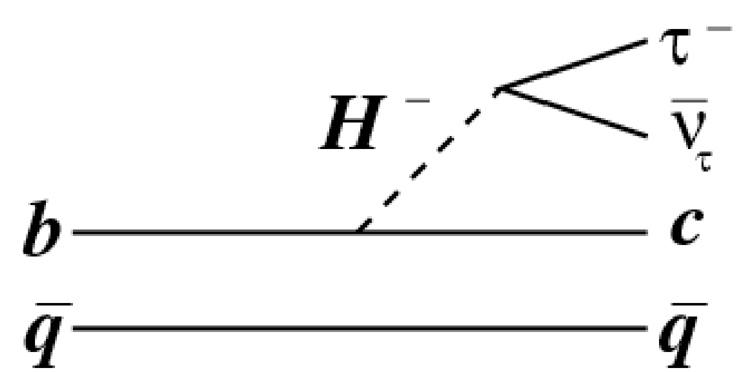


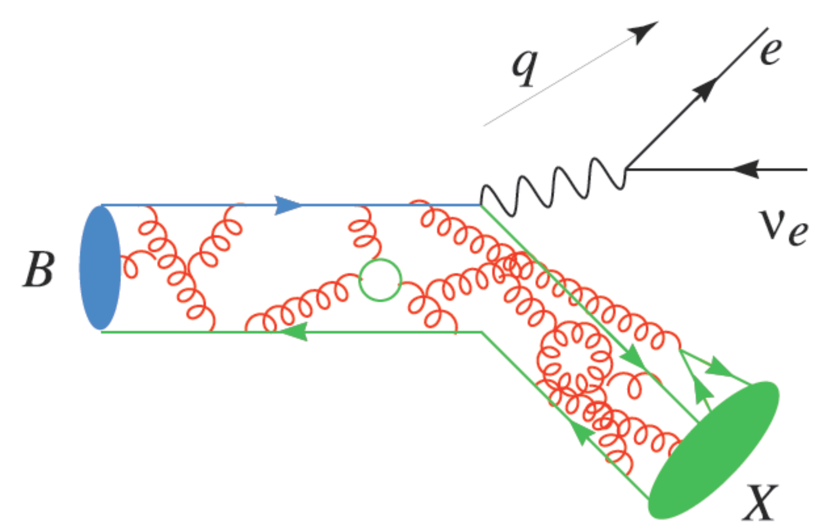


$B \to D^{(*)}\tau\nu$: Motivation (II)

- ratio $B \to D^{(*)}\tau\nu / B \to D^{(*)}l\nu$
  - phase space reduced
  - additional helicity for W
    - two form factors for D, four for D*
    - HQET relates these extra FF to “light lepton” FF’s
- spin 0 Higgs does not couple to all helicity states
  - effect on D and D* different

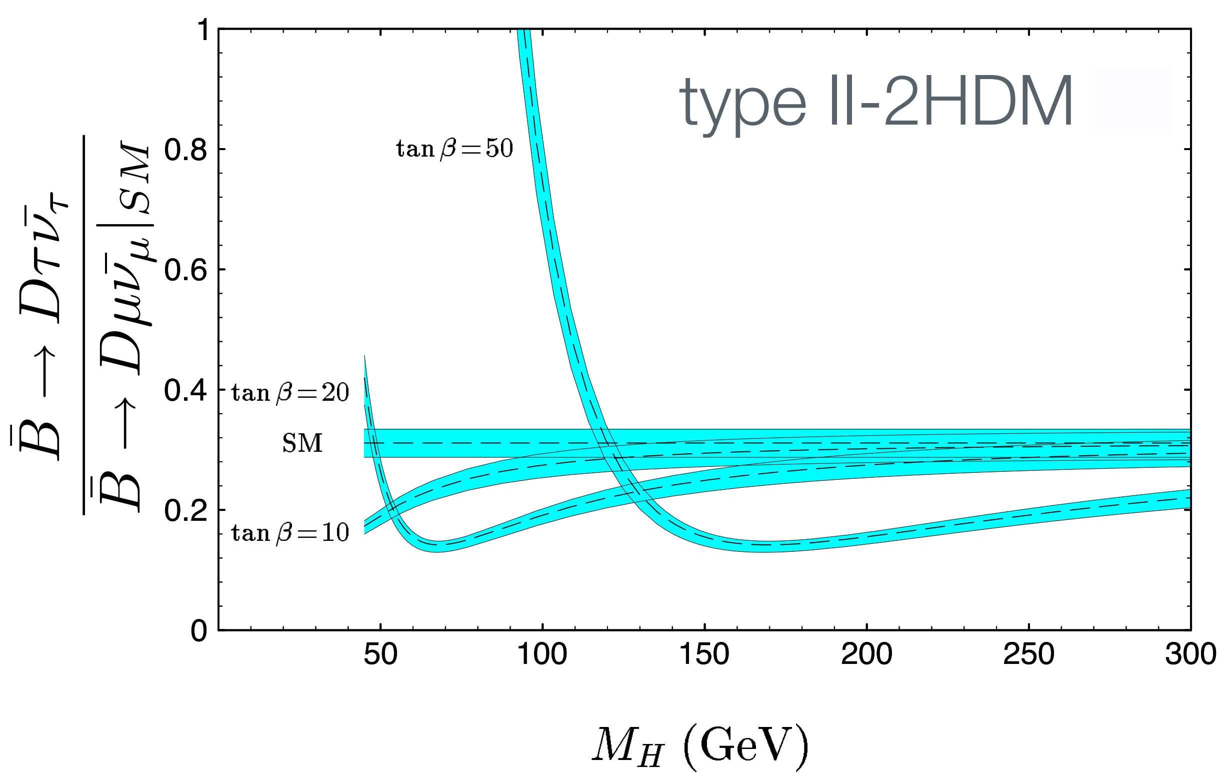
Decay Mode	$\mathcal{B}$ (%)
$\overline{B}^0 \to D^- \tau^- \overline{\nu}_\tau$	0.69 ± 0.04
$\overline{B}^0 \to D^{*-} \tau^- \overline{\nu}_\tau$	1.41 ± 0.07
$B \to X_c \tau^- \overline{\nu}_\tau$	2.3 ± 0.25

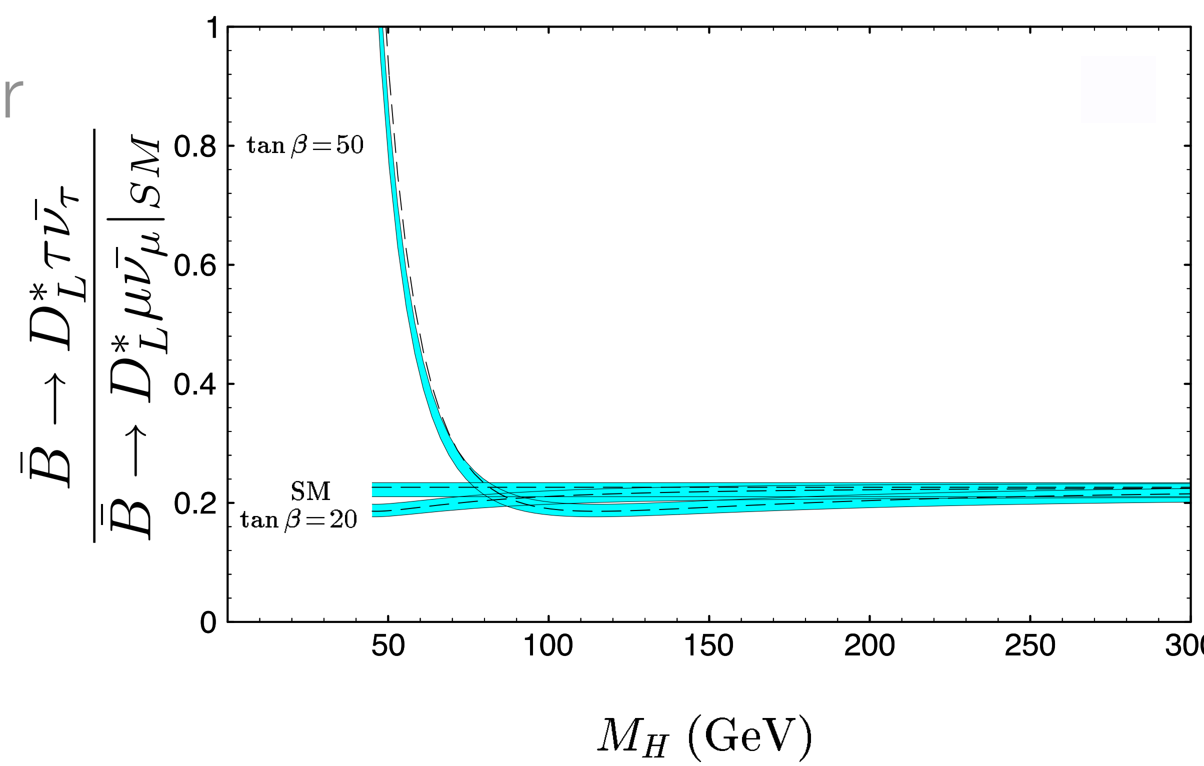




$B \to D^{(*)}\tau\nu$: Motivation (III)

- presence of Higgs changes branching fraction
- here shown for 2HDM
    - other models show similar behavior





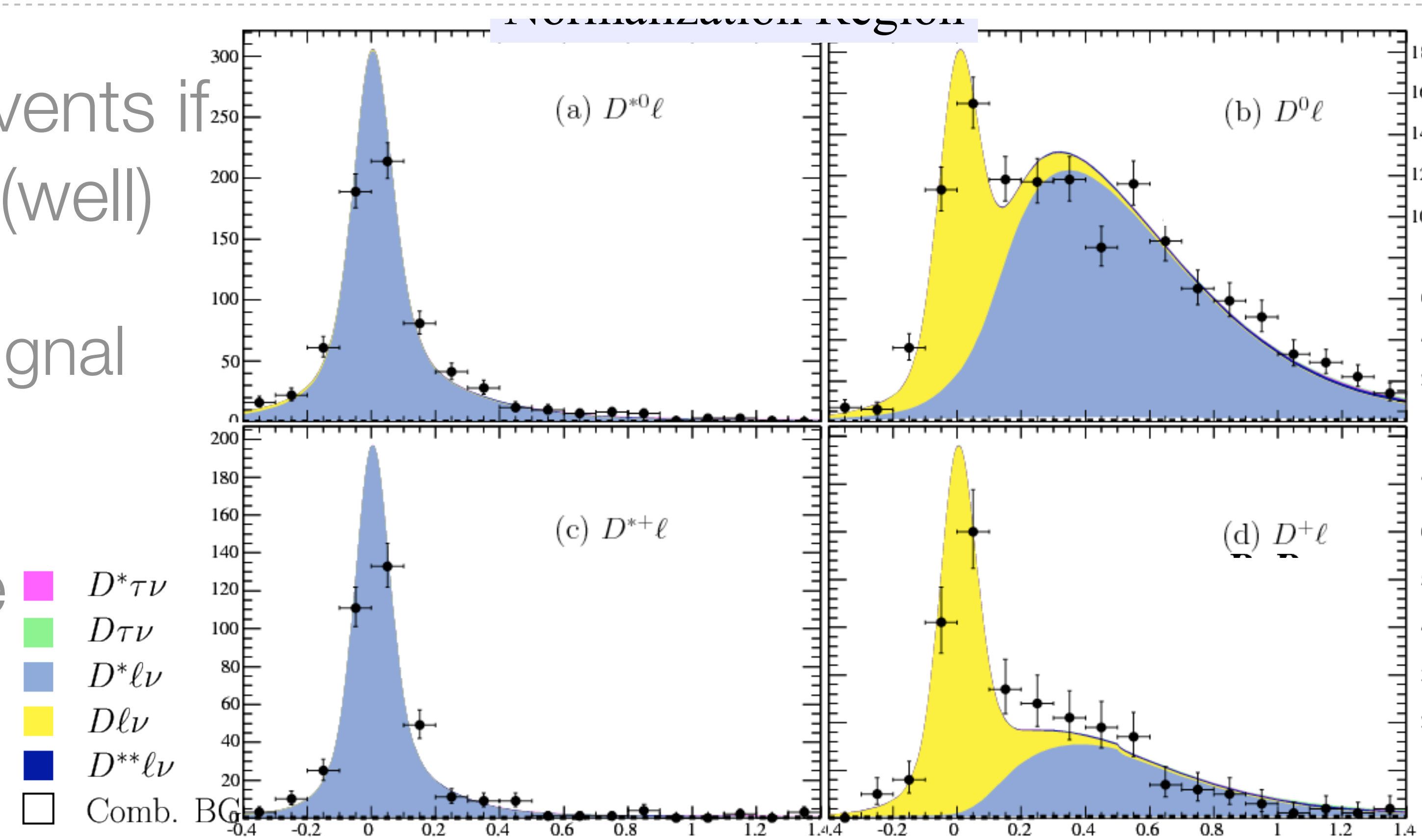
plots from Tanaka,
Z Phys C67 321 (1995)

$B \to D^{(*)} \tau \nu$: Analysis Outline

- use a hadronic Tag-B
- reconstruct a $D^{(*)}$ l candidate from recoil particles
  - l = e or μ, lepton could be primary or from τ-decay
- event selection
  - require $p_{Miss} > 200$ MeV and $q^2 > 4$ GeV^2, all tracks belong to either Tag or Signal B
- m^2_{Miss} is zero for primary decays, signal events form tail out to 8 $(GeV/c^2)^2$
- lepton momentum of primary leptons is higher
  - do a combined fit of m_{Miss} and the lepton momentum

$B \to D^{(*)}\tau\nu$: Cross-feeds and Backgrounds

- D^* events can feed down to D events if soft γ or π^0 is not reconstructed (well)
  - true for both background and signal modes
- smaller feed-up components are present
- other backgrounds
  - D**, D(*) Ds(*), charge cross-feed
  - construct D** control sample by requiring an extra π^0



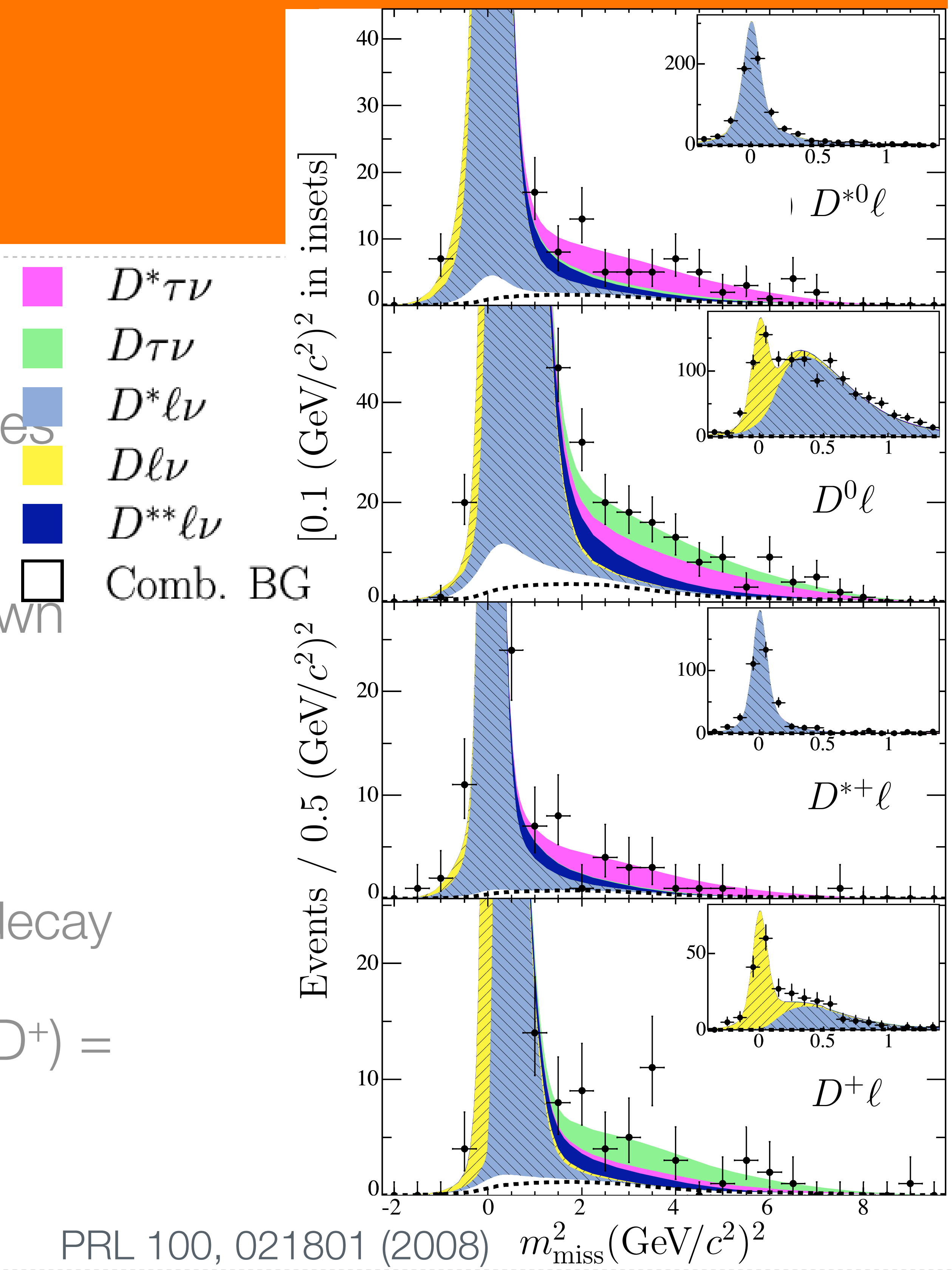
PRL 100, 021801 (2008)

m^2_{Miss}~0: normalization region

- charm resonances heavier than D*(2010)
- non-resonant $D^*n\pi$ ($n \geq 1$)

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

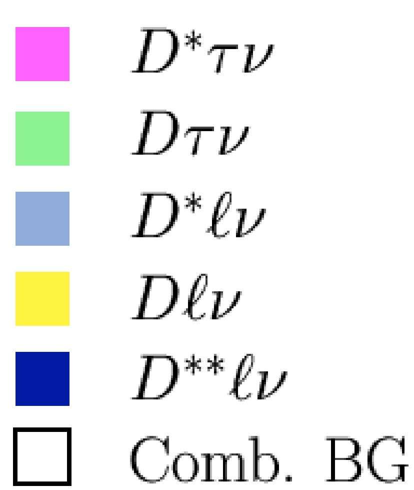
- fit all 4 channels simultaneously
- use 7 components (dashed line indicates charge cross-feed)
- parameters of most important feed-down component is floated in the fit
- fit includes D** samples
  - less sensitivity to details of prod. and decay
- perform two fits, one with the ratios R(D+) = R(D0) and R(D*+) = R(D*0)
  - latter fit is shown on left

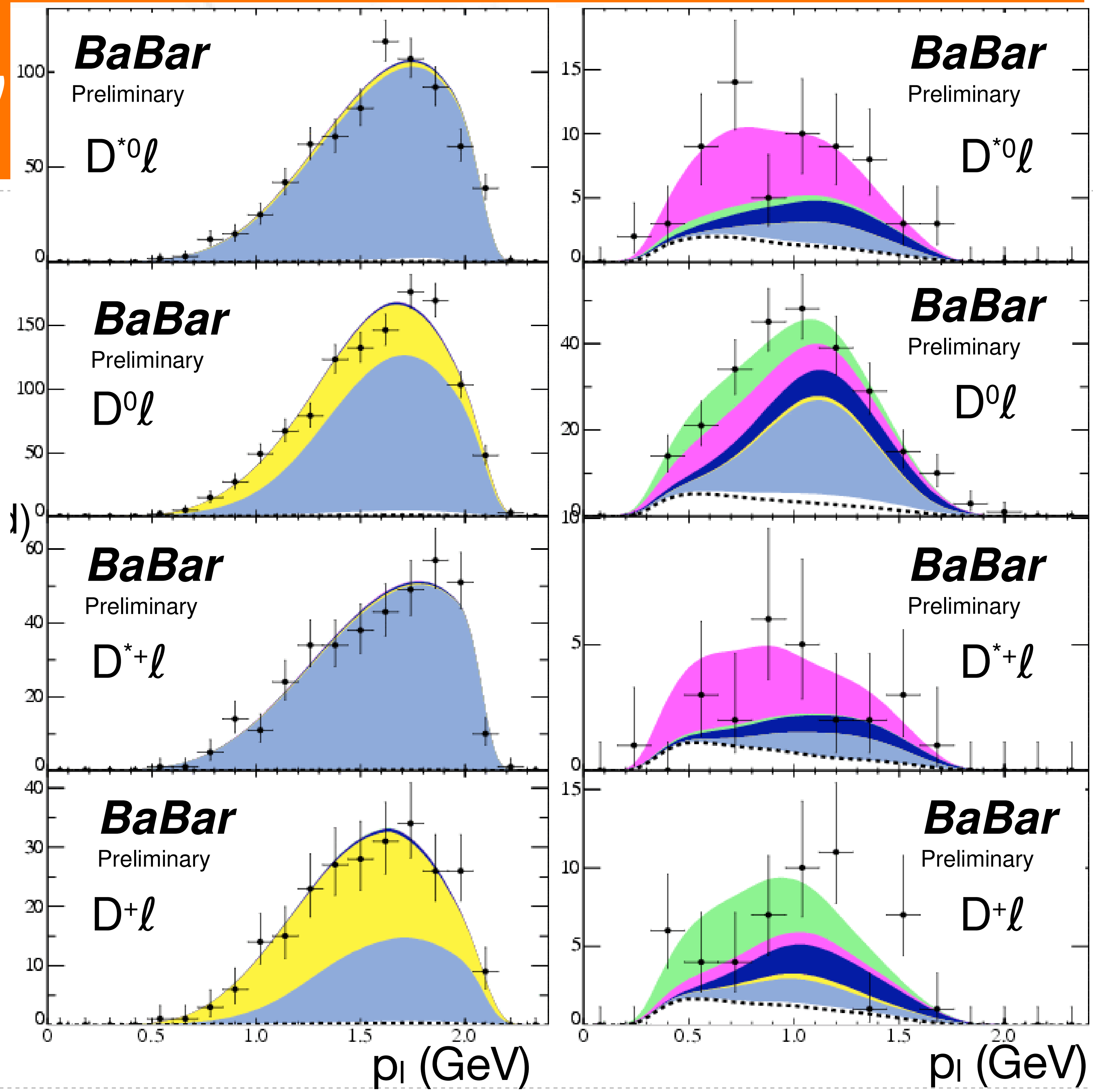


PRL 100, 021801 (2008)

B→D(*)τν

- left: Normalization Region
  - low missing invariant mass squared
- right: Signal Region
  - high missing invariant mass squared





$B \to D^{(*)} \tau \nu$: Systematics and Final Result

- many systematics (tracking, particle identification) mostly cancel in ratio
- uncertainties on fit estimated by ensembles of fits
  - PDF parametrization (2-12%)
  - composition of combinatoric background (2-11%)
  - D^{**} composition (0.3-6%)
  - π^0 efficiency (effect on feed-down)
  - B D(*) form factors (<2%)
  - m_{Miss} resolution

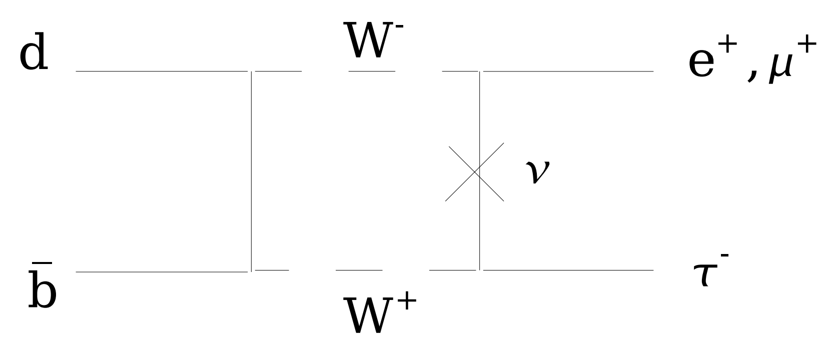
Mode	$\mathcal{B}$ [%]	σ_{tot} (σ_{stat})
$B^- \to D^0 \tau^- \overline{\nu}_\tau$	$0.67 \pm 0.37 \pm 0.11 \pm 0.07$	1.8 (1.8)
$B^- \to D^{*0} \tau^- \overline{\nu}_\tau$	$2.25 \pm 0.48 \pm 0.22 \pm 0.17$	5.3 (5.8)
$\overline{B}^0 \to D^+ \tau^- \overline{\nu}_\tau$	$1.04 \pm 0.35 \pm 0.15 \pm 0.10$	3.3 (3.6)
$\overline{B}^0 \to D^{*+} \tau^- \overline{\nu}_\tau$	$1.11 \pm 0.51 \pm 0.04 \pm 0.04$	2.7 (2.7)
$B \to D \tau^- \overline{\nu}_\tau$	$0.86 \pm 0.24 \pm 0.11 \pm 0.06$	3.6 (4.0)
$B \to D^* \tau^- \overline{\nu}_\tau$	$1.62 \pm 0.31 \pm 0.10 \pm 0.05$	6.2 (6.5)

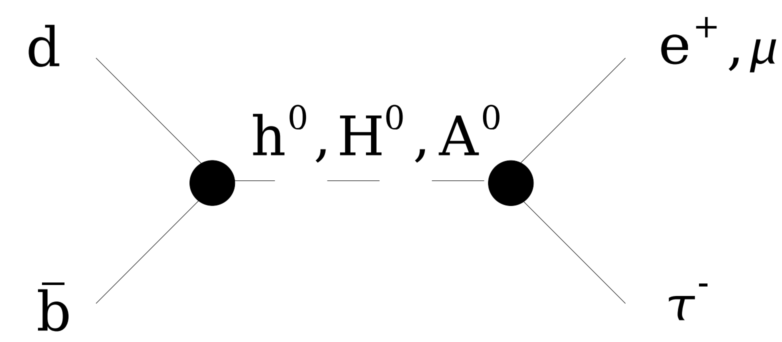
errors:
stat, sys and from normalization mode
Result uses 232 M BB

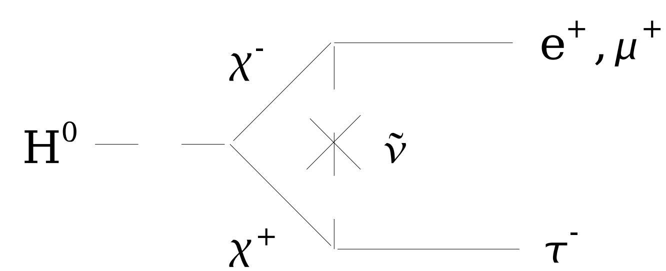
Belle (535 M BB):

$$\mathcal{B}(B^0 \to D^{*-} \tau^+ \nu_\tau) = (2.02^{+0.40}_{-0.37}(stat) \pm 0.37(syst))\%$$

$B^0 \to e/\mu\ \tau$: Motivation



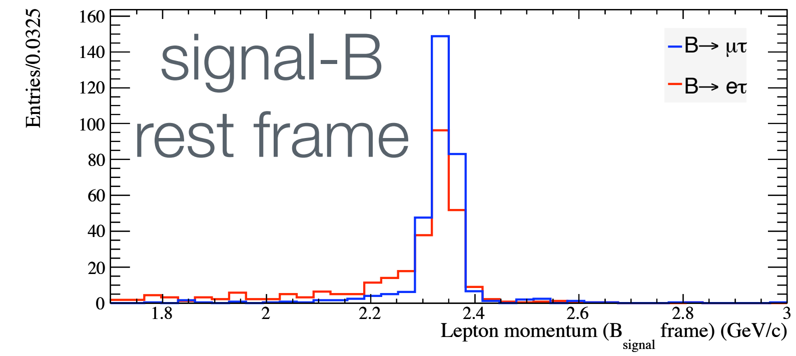


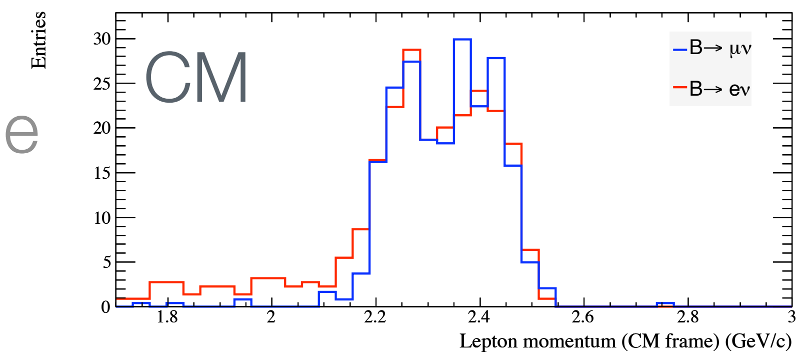


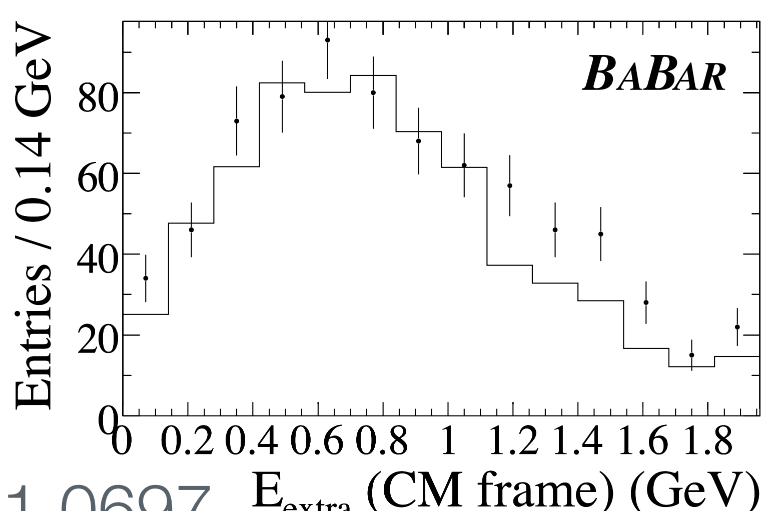
- lepton number violating decay
  - in Standard Model only allowed via neutrino oscillations
  - in SUSY, the LFV could be in the slepton sector
    - other LFV decays suppressed by m^2_l/m^2_τ (for $B^0 \to e\mu$ factor is ~ 0.0036)
- theoretical prediction in flavor-universal MSSM ~2 x 10^{-10}
- previous best limits set by CLEO: $\mathcal{B}^{90\% C.L.}(B \to e/\mu\ \tau) < 11/3.8 \times 10^{-5}$ $(10\ fb^{-1})$

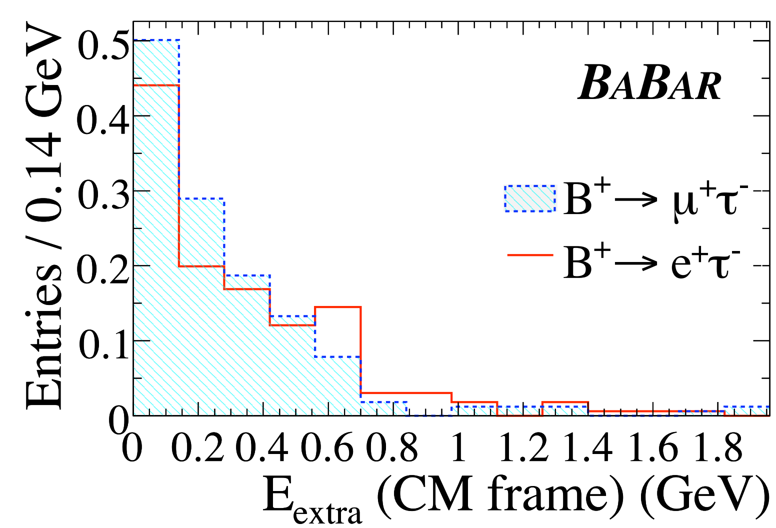
$B^0 \to e/\mu\ \tau$: Measurement

- work in the recoil of a (neutral) hadronic Tag-B
- in this sample, the signal-B rest frame is fully determined
    - lepton momentum (of e/μ) peaks in signal-B rest frame (2-body decay)
- use presence of lepton + τ-daughters and nothing else in the recoil to select event
- fit the lepton momentum







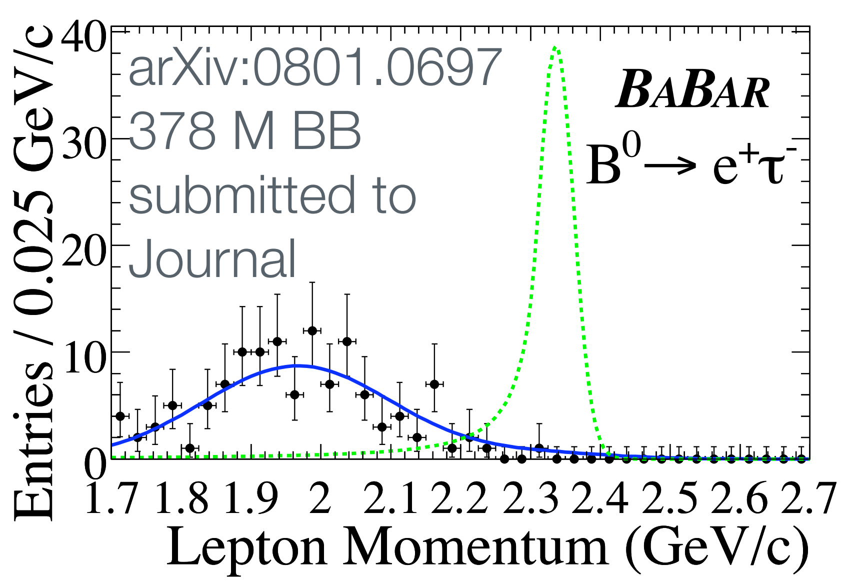


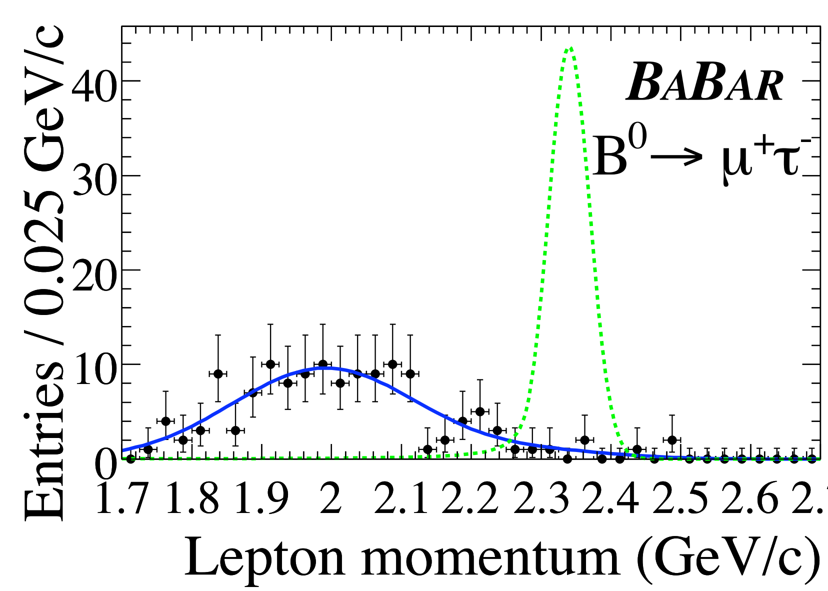
arXiv:0801.0697

$B^0 \rightarrow e/\mu\ \tau$: Result

- unbinned maximum likelihood fit to the lepton momentum in the B_{signal} frame
- signal modeled by Crystal Ball function to account for energy loss due to bremsstrahlung, background modeled by double gaussian
- limit is extracted from events in the signal region 2.2GeV/c < p*< 2.42 GeV/c
- $\mathcal{B}^{90\%C.L.}(B \rightarrow e/\mu\ \tau) < 2.8/2.2 \times 10^{-5}$, (CLEO: $\mathcal{B} < 11/3.8 \times 10^{-5}$)

Uncertainty source	$e^+\ \tau^-$	$\mu^+\ \tau^-$
Signal Fit	5.6	10.6
Background Fit	3.9	3.1
B_{tag} efficiency	6.4	6.4
PID efficiency	5.3	5.8
MC Statistics	8.6	7.4
Tracking efficiency	1.7	1.7
$N_{B\bar{B}}$	1.1	1.1

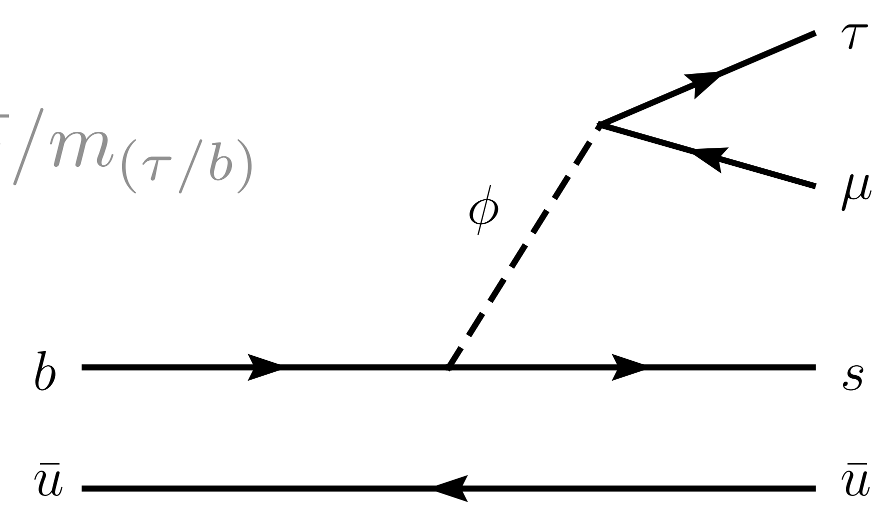




B→Kμτ: Motivation

Sher/Yuan PRD44, 1461 (1991)

- GUT introduces FCNC at tree level
- natural value of Yukawa couplings $\eta_{ij} = \sqrt{m_i m_j}/m_{(\tau/b)}$
  - quark and lepton couplings equal at GUT scale
  - B→Kμτ $\propto \eta^2_{\mu\tau} \times \eta^2_{\mu\tau}$



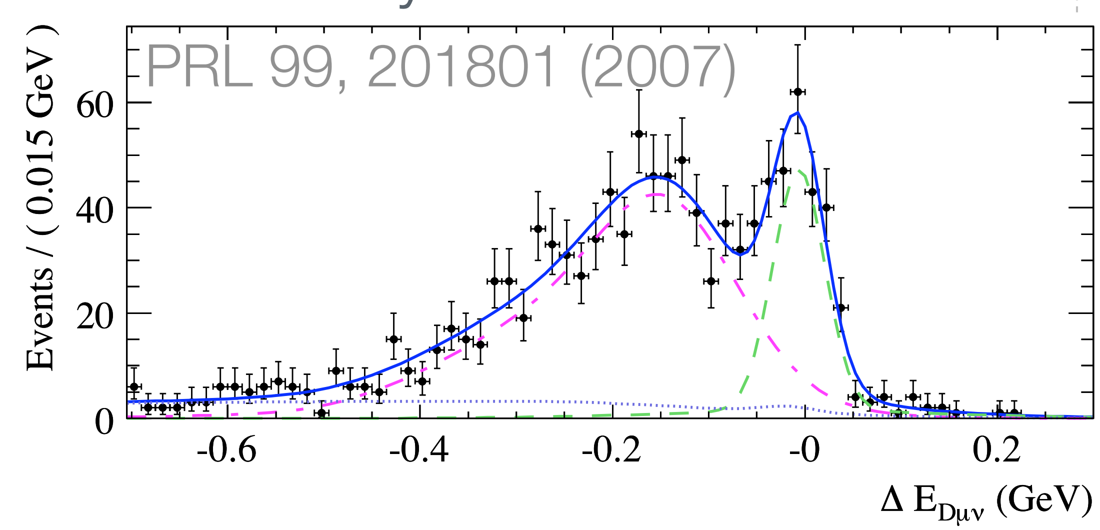
- K*ll* analysis set limit on Keμ
  - experimentally easier, but suppressed by $\approx (m_e/m_\tau)$
- Bs→μμ competitive $\propto \eta^2_{\mu\tau} \times \eta^2_{\mu\mu}$, suppressed only by $\approx (m_\mu/m_\tau)$
  - Tevatron limit very low, but tests different couplings and “naturalness” might not be exact in nature

B→Kμτ: Measurement

- work in the recoil of a hadronic Tag-B
  - kinematics of the Signal-B are determined
  - calculate τ-kinematics from Tag-B, K and μ
    - $m_\tau = \sqrt{E_\tau^2 - p_\tau^2}$ peaks at τ-mass in signal events
- require 3 tracks in the recoil,
  - one passing K and another μ PID criteria
  - the tau daughter track can be either an electron, μ or π
    - control sample from $B \to D^{(*)0}\mu\nu_\mu$ with $D^0 \to K^+\pi^-$

unbinned likelihood fit for yields

- - - - - D^0
- - - - - D^{*0}



$\Delta E_{D\mu\nu} = E_K + E_\mu + E_\pi + p_\nu - E_{beam} = p_\nu - E_{miss}$

B→Kμτ: Result

- reject events from $B \to D^{(*)0}\mu\nu_\mu$ with $D^0 \to K^+\pi^-$ by cut on $m(K\pi)$
- Charmonium veto in μ and π channel
- Likelihood-variable to reject continuum background using E_{extra}, lepton-ID and cos Θ^*_T ($\cos\alpha(\text{Thrust}_{TagB}, \text{Thrust}_{ROE})$)
- estimate background from sidebands in m_τ
- signal branching fraction

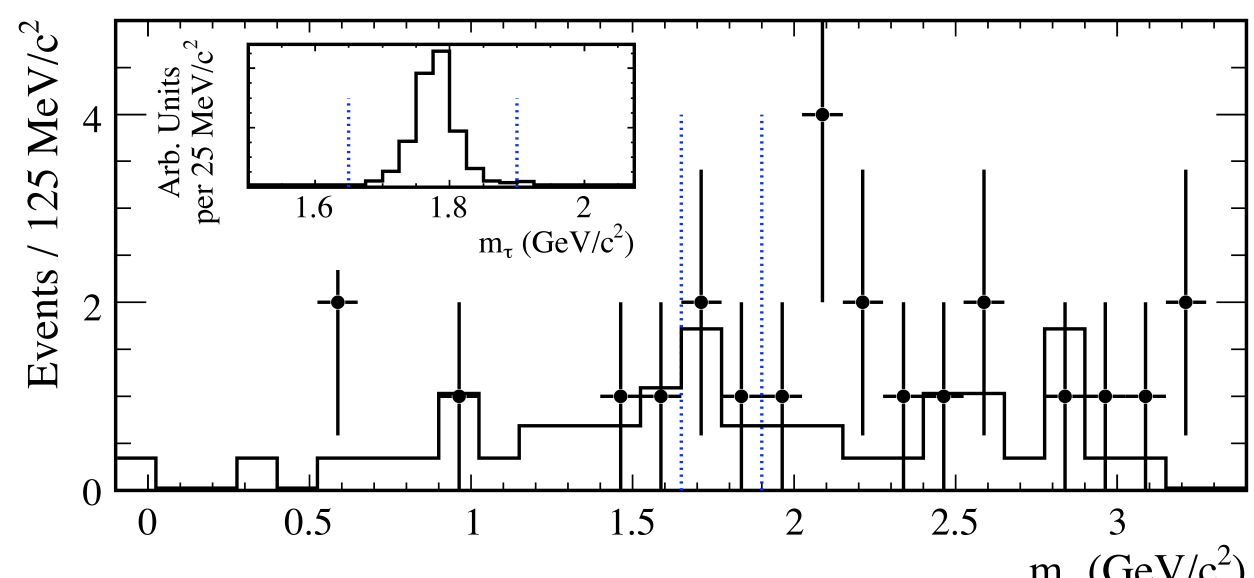
$$\mathcal{B}_i = (n_i - b_i)/(\epsilon_i S_0)$$

$$S_0 = \frac{N_{D\mu\nu}}{\mathcal{B}_{D\mu\nu}}\left(\frac{1}{\epsilon_{D\mu\nu}}\right)\left(\frac{\epsilon_{tag}^{K\mu\nu}}{\epsilon_{tag}^{D\mu\nu}}\right)$$

control sample

- many systematics cancel in ratio

PRL 99, 201801 (2007)



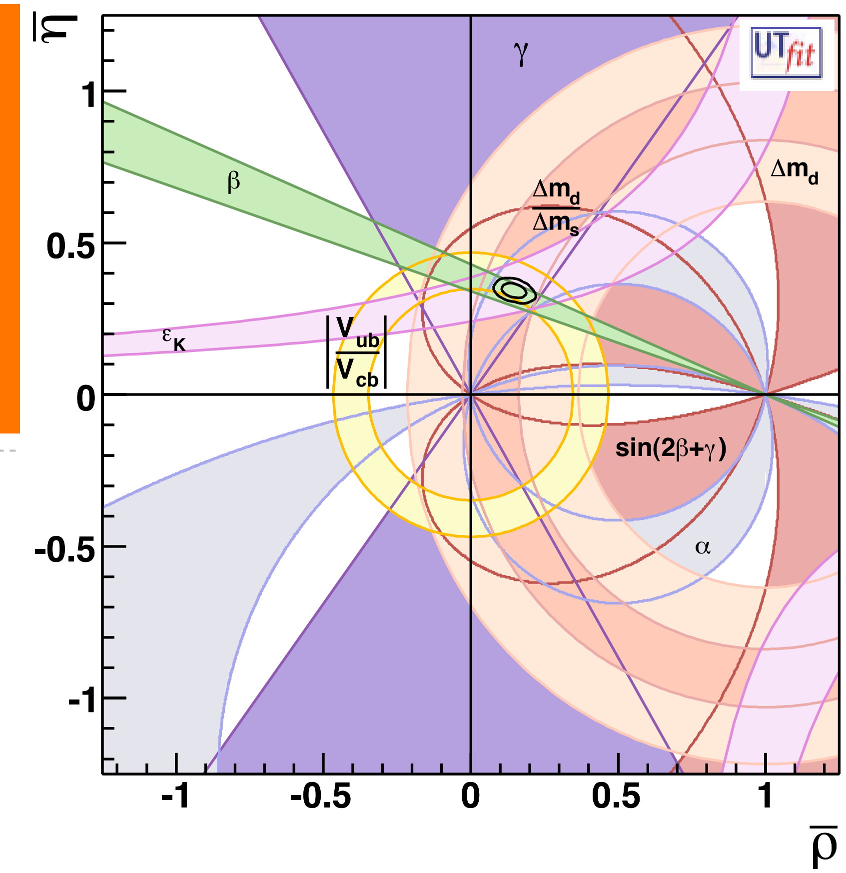
$$\mathcal{B}^{90\%C.L.}(B \to K\mu\tau) < 7.7 \times 10^{-5}$$

Interpretation and Outlook

$B \to \mu\tau$, $B \to K\mu\tau$

- motivated by neutrino oscillations, a model-independent framework for lepton flavor changing neutral current has been proposed in Black, Han, He and Sher, PRD66, 052003 (2002)
  - expresses connection of BF and the energy scale of new physics operators Λ_{ij}
- $B^0 \to e/\mu\tau$ limits most stringent to date (~ $2.8/2.2 \times 10^{-5}$)
  - moves limit for $\Lambda > 8.2$ TeV to $\Lambda > 11.6$ TeV for the Λ_{bd} operator
  - still orders of magnitude away from theoretical predictions (MSSM: O 10^{-10})
  - in currently considered models.....
- (first) $B^+ \to K\mu\tau$ limit $\mathcal{B}^{90\% C.L.}(B \to K\mu\tau) < 7.7 \times 10^{-5}$
  - moves limit for from $\Lambda > 2.6$ TeV to $\Lambda > 13$ TeV for the Λ_{bs} operator

B→τν and Lattice QCD

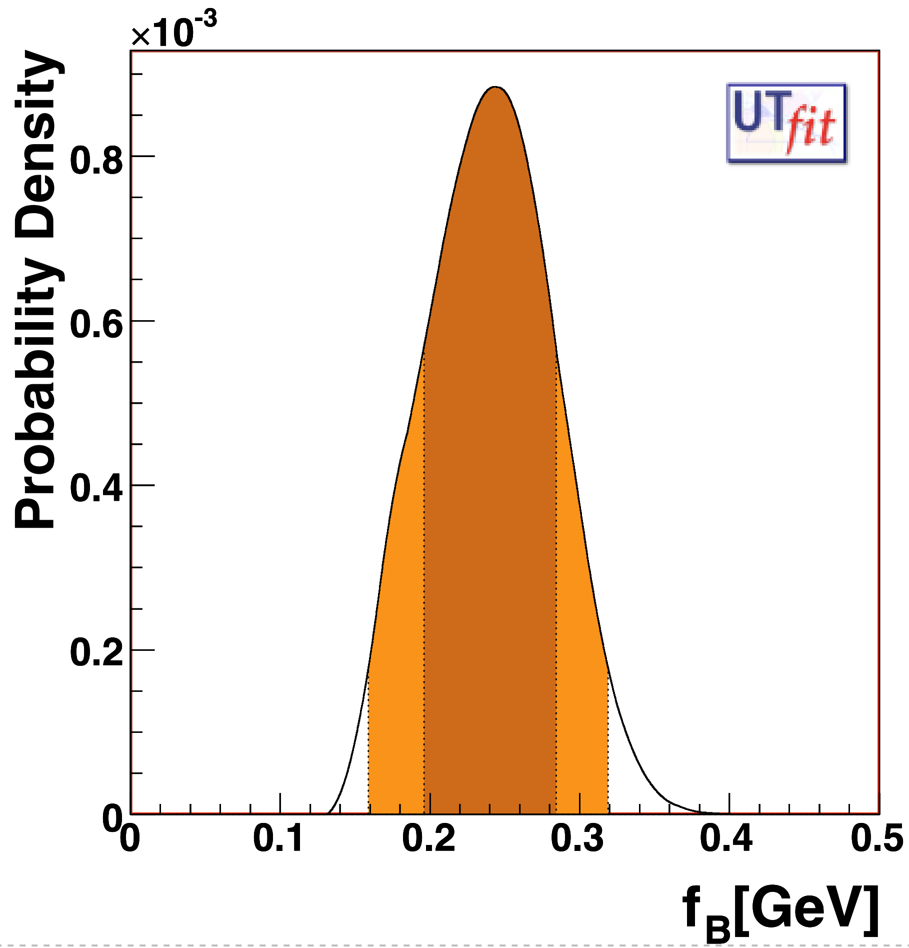


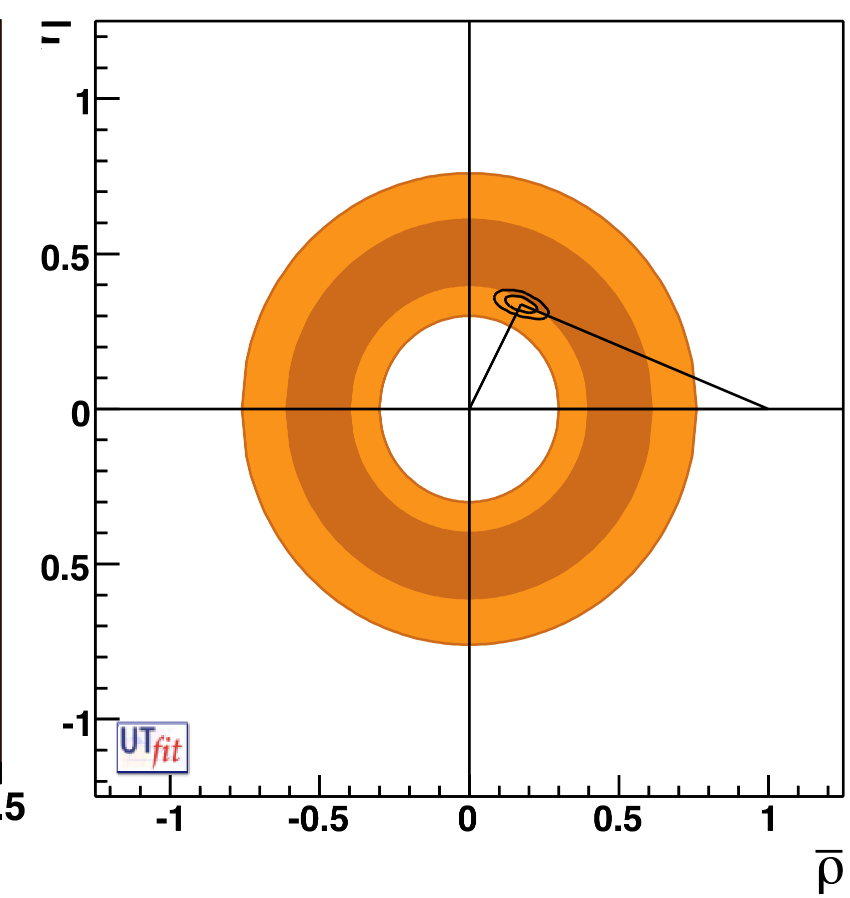
- use the measured branching fraction and the UTfit angle fit into a prediction of f_B
  - $f_B = 0.24 \pm 0.044$ GeV
- Lattice QCD
  - $f_B = 0.216 \pm 0.022$ GeV

Phys.Rev.Lett.95:212001,'05. (HPQCD)

  - $f_B = 0.189 \pm 0.027$ GeV

Int.J.Mod.Phys. A20:(5133-5144),'05.





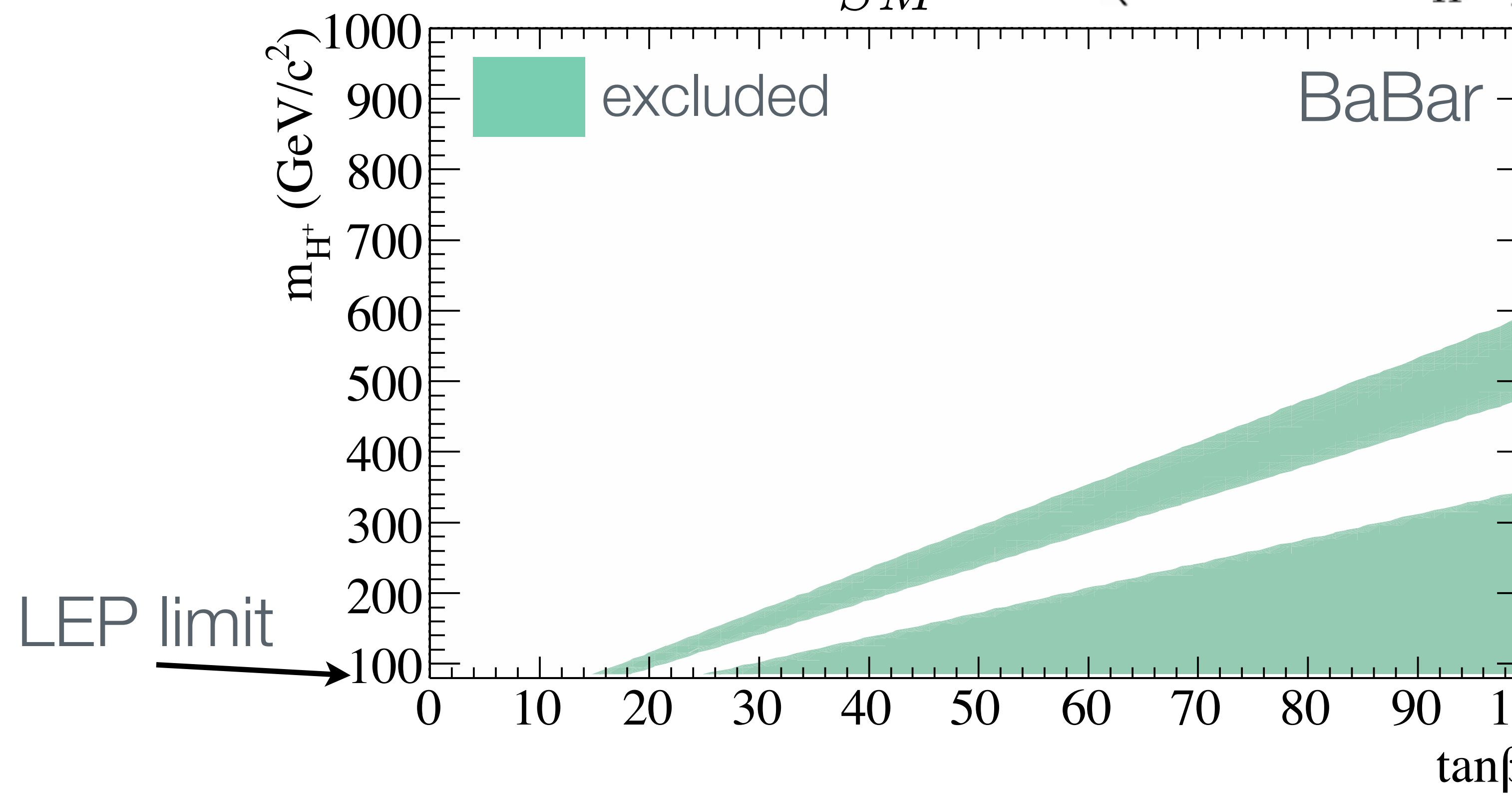
B→τν and Higgs

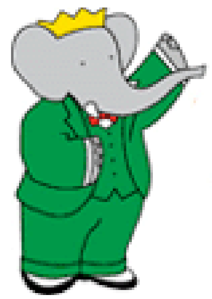
- BaBar
  - semileptonic + hadronic tag combined:

$$(1.2 \pm 0.4_{stat} \pm 0.3_{bkg} \pm 0.2_{syst}) \times 10^{-4}$$

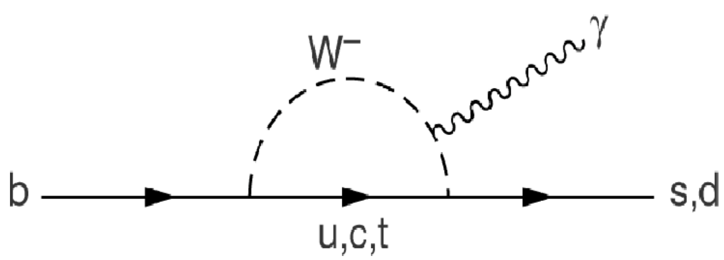
$$\frac{BF_{NP}}{BF_{SM}} = \left(1 - \tan^2\beta \frac{m^2_{B^\pm}}{m^2_{H^\pm}}\right)^2$$

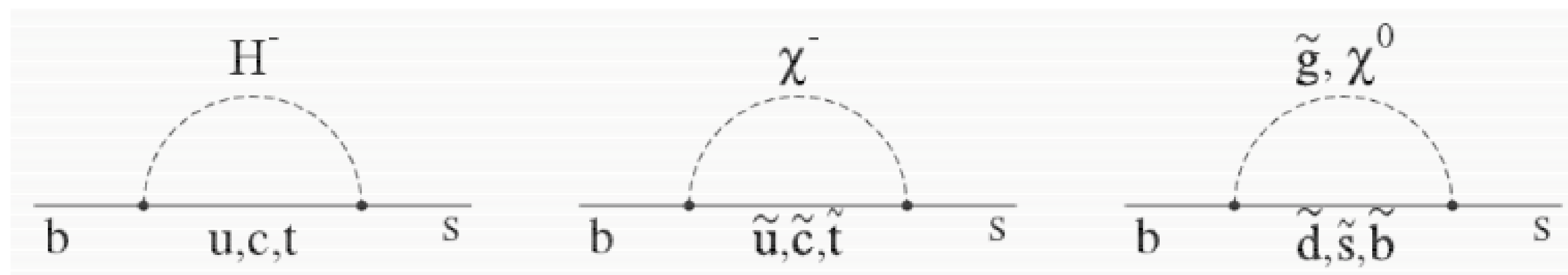
- add b→sγ information





Why b→sγ ?





- flagship of FCNC: in SM only allowed at loop-level
- no GIM suppression in top-loop
  - experimentally accessible
- with additional non-SM particles, many more loops possible
  - strong limit, model dependent
- best current (BaBar) measurements use 88M BB events

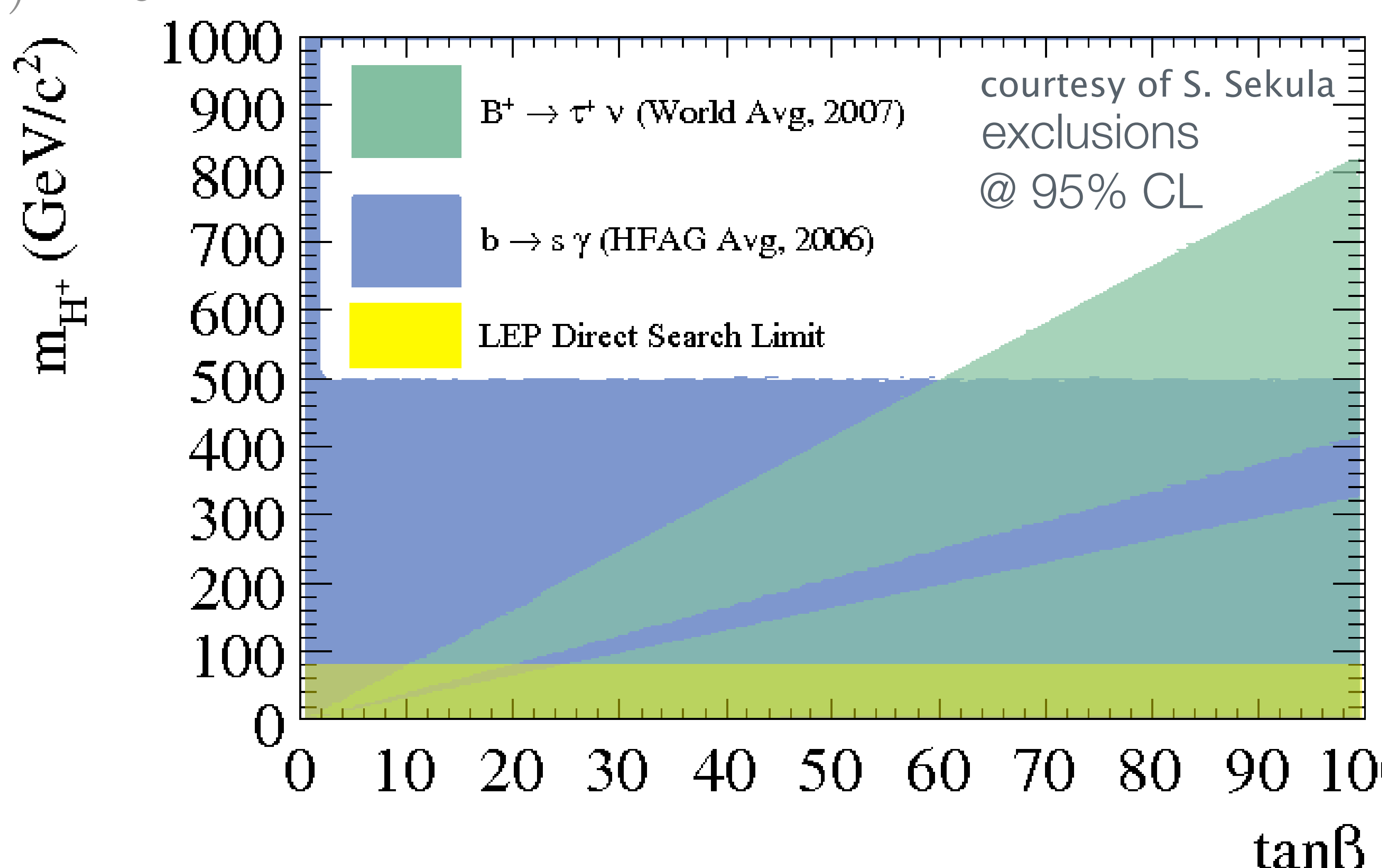
$$\mathrm{BF}(B \to X_s\gamma)[E_\gamma > 1.9\ GeV] = 3.67 \pm (\underset{\text{(stat)}}{0.29} \pm \underset{\text{(sys)}}{0.34} \pm \underset{\text{(model)}}{0.29}) \times 10^{-4}$$ (incl.)

B→τν and b→sγ in the 2HDM

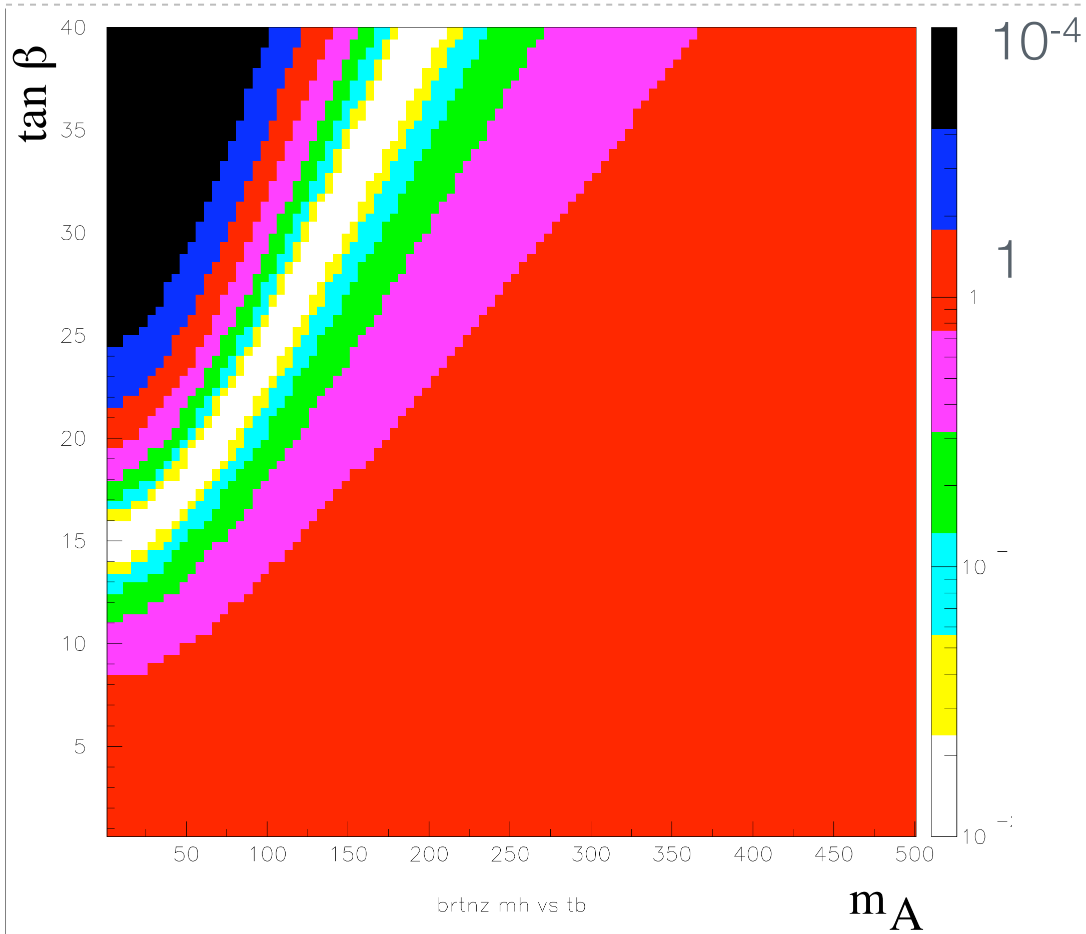
Theoretical prediction,
Becher and Neubert, PRL 98, 022003 (2007)
$\mathrm{BF}(B \to X_s\gamma) = (2.98 \pm 0.26) \times 10^{-4}$

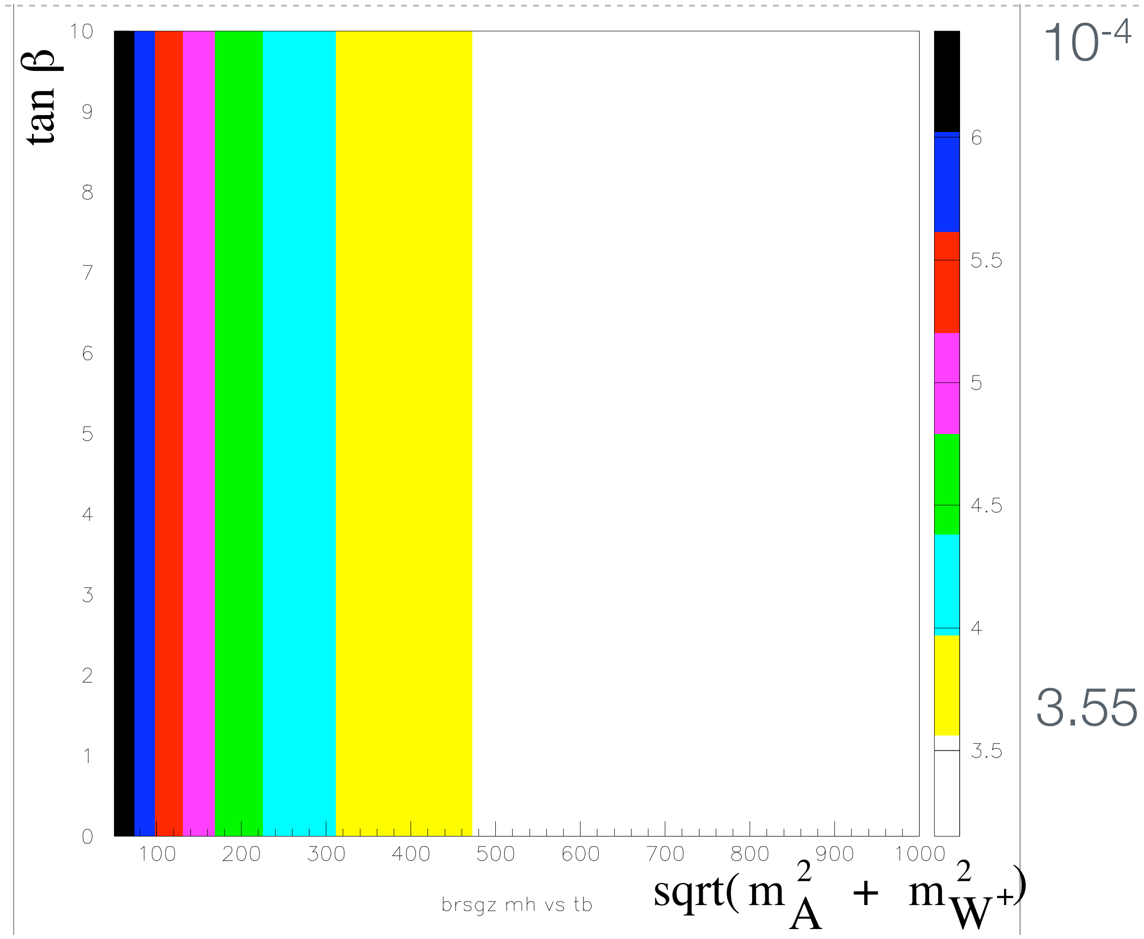
Barberio *et al*, HFAG,
hep-ex/0603003
$\mathrm{BF}(B \to X_s\gamma) = (3.55 \pm 0.24^{+0.09}_{-0.1} \pm 0.02) \times 10^{-4}$

Belle (prelim, Mor EW 08)
$\mathrm{BF}(B \to X_s\gamma) = (3.31 \pm 0.16 \pm 0.37 \pm 0.01) \times 10^{-4}$



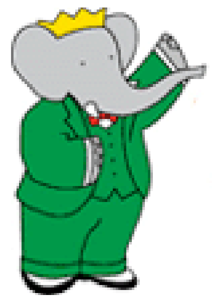
B→τν, b→sγ and model-dependence



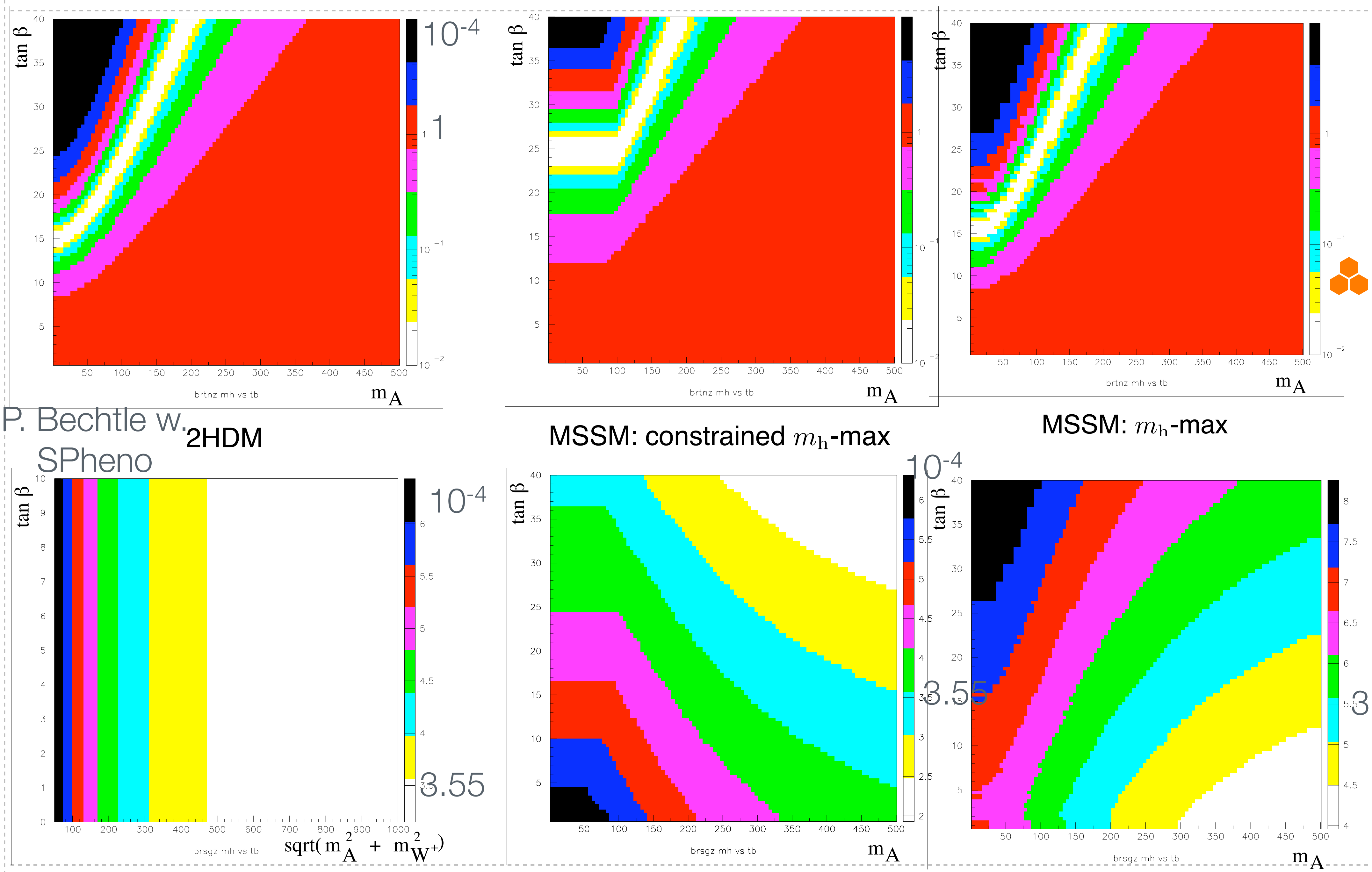


P. Bechtle w. SPheno

- predictions for the B→τν and b→sγ BF as functions of the Higgs mass ma and tanβ
  - here for the 2HDM

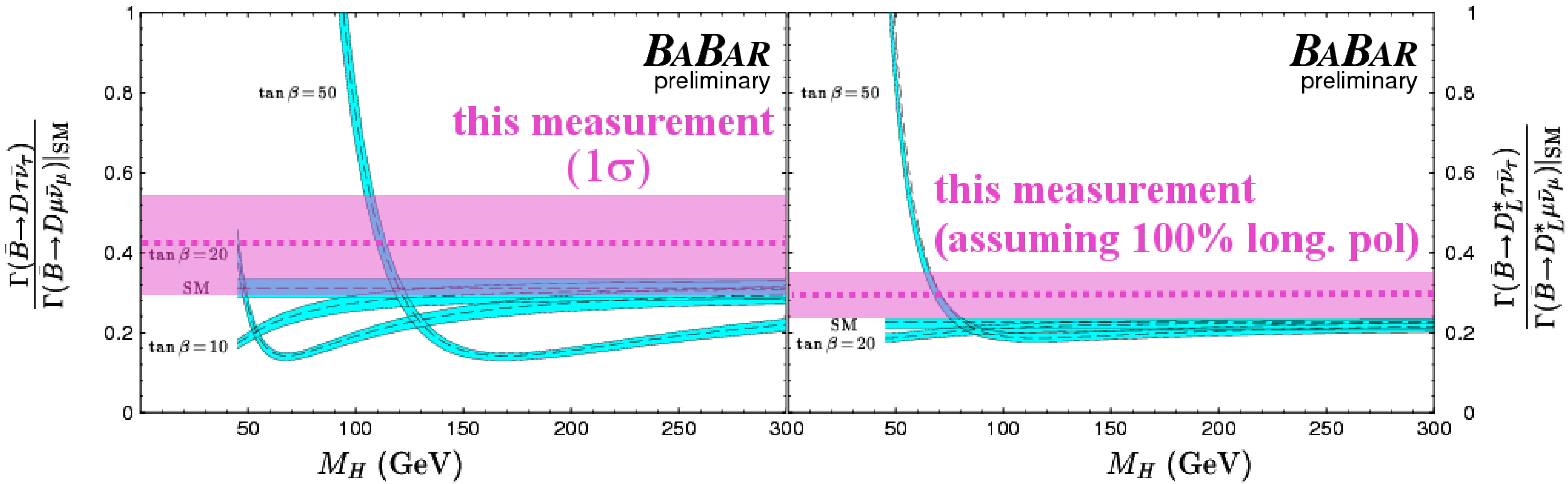


B→τν, b→sγ and model-dependence



- these measurements combined teach us about the nature of the NP sector

B→D(*)τν: Interpretation



- blue bands in theory prediction dominated by form factors
  - to be improved new measurements

Conclusions

- knowledge about B-decays with τ-leptons has increased recently
  - for both “measurement” and “search” channels
- no deviation from the Standard Model has been found
- leading to improvements of limits on new physics in lepton flavor violating decays
- results in “measurement” channels can be translated in constraints on the charged Higgs
  - will help to interpret signs of “new physics” together with other measurements such as $b \to s\gamma$

Outlook - BaBar...

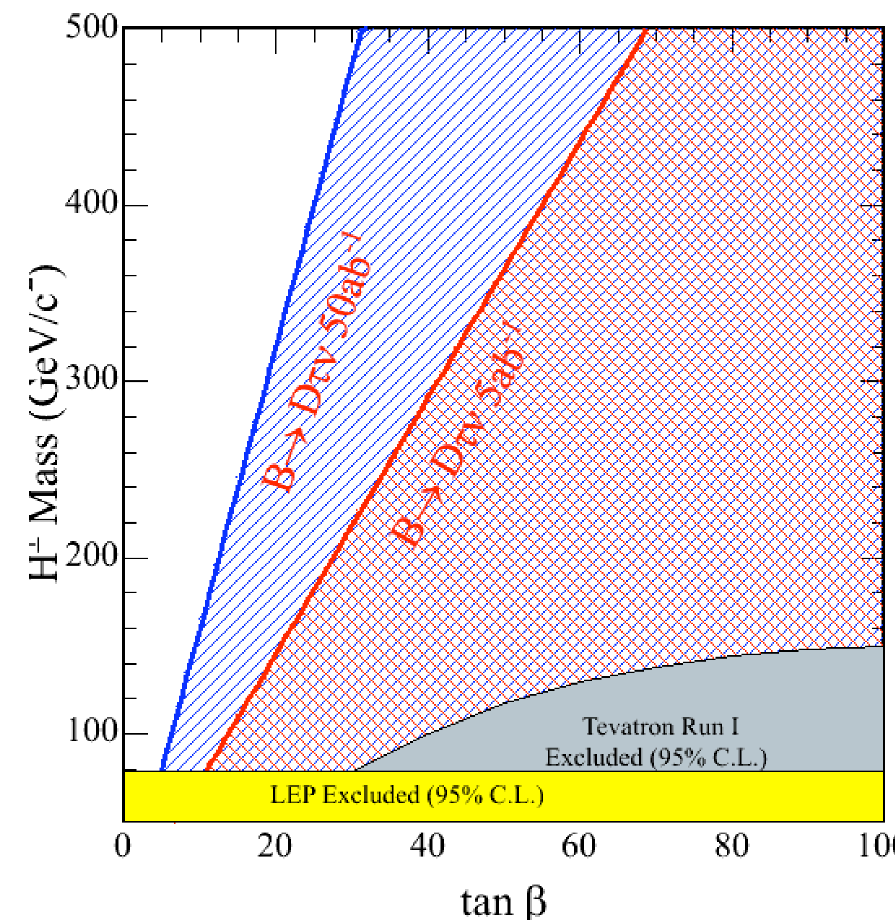
- expect updates using the final data sample for $B \to \tau\nu$ and $B \to D\tau\nu$
- add electron channel to $B \to K$"μ"τ

- improvements in charged particle identification
  - in particular low momentum muons
- higher hadronic tag efficiency
- study of multivariate methods

- look forward to significant signal in $B \to \tau\nu$...

Outlook - ... and Beyond

- Belle will continue to take data
- KEK plans: upgrade from second half of 2008-2012 to SuperKEKB
- Super*B* factory (INFN Frascati)
- if NP is seen directly, SuperFlavorFactory (SFF) can help to understand detailed structure of underlying model
- sensitive to multi-TeV NP even in absence of direct observations



arXiv[hep-ph]:0710.3799

Observable	Super Flavour Factory sensitivity
$\mathcal{B}(B \to \tau\nu)$	3–4%
$\mathcal{B}(B \to \mu\nu)$	5–6%
$\mathcal{B}(B \to D\tau\nu)$	2–2.5%

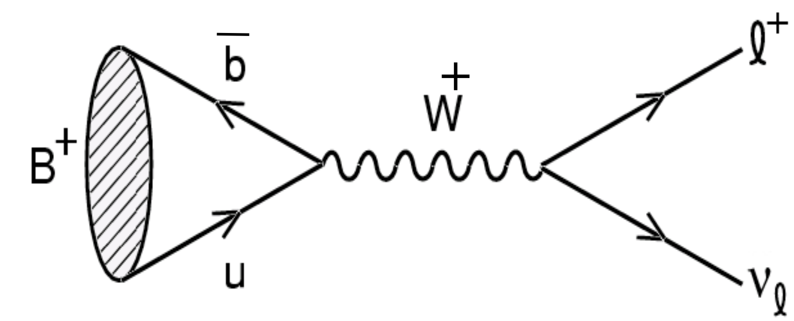
Backup

2 Higgs Doublet Model

- Straight forward extension to SM
- Model I: Fermions couple to only one of the doublets
  - interesting region excluded by $b \rightarrow s\, \gamma$
- Model II: One doublet gives mass to down-type quarks, second to top-type quarks
  - $v^2 = v_1^2 + v_2^2$ and $\tan\beta = v_2/v_1$
    - coupling to taus enhanced for large $\tan\beta$
  - building block for MSSM
  - 5 physical states: CP-even H^0 and h^0, CP-odd A and charged $H^\pm$

Motivation - Why Taus?

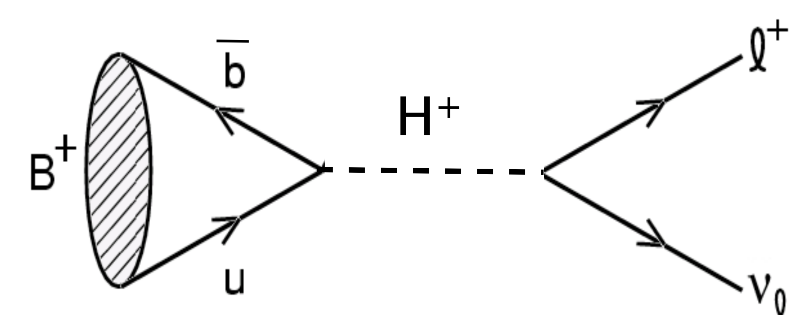
- + helicity suppression in leptonic decays relieved for more massive τ - relatively large BF



- + stronger coupling to Higgs-like particles

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

  - look at type II 2HDM: simplest model with extended Higgs sector
    - similar to Higgs sector in MSSM



Nierste (et al), hep-ph arXiv:0801.4938

MSSM w. MFV

$$g_S = g_P = \frac{m_B^2}{m_{H^+}^2} \frac{\tan^2\beta}{(1+\tilde{\epsilon}_0 \tan\beta)(1+\epsilon_\tau \tan\beta)}$$

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

W.-S. Hou, Phys. Rev. D. Brief Report 48 (1993) 2342

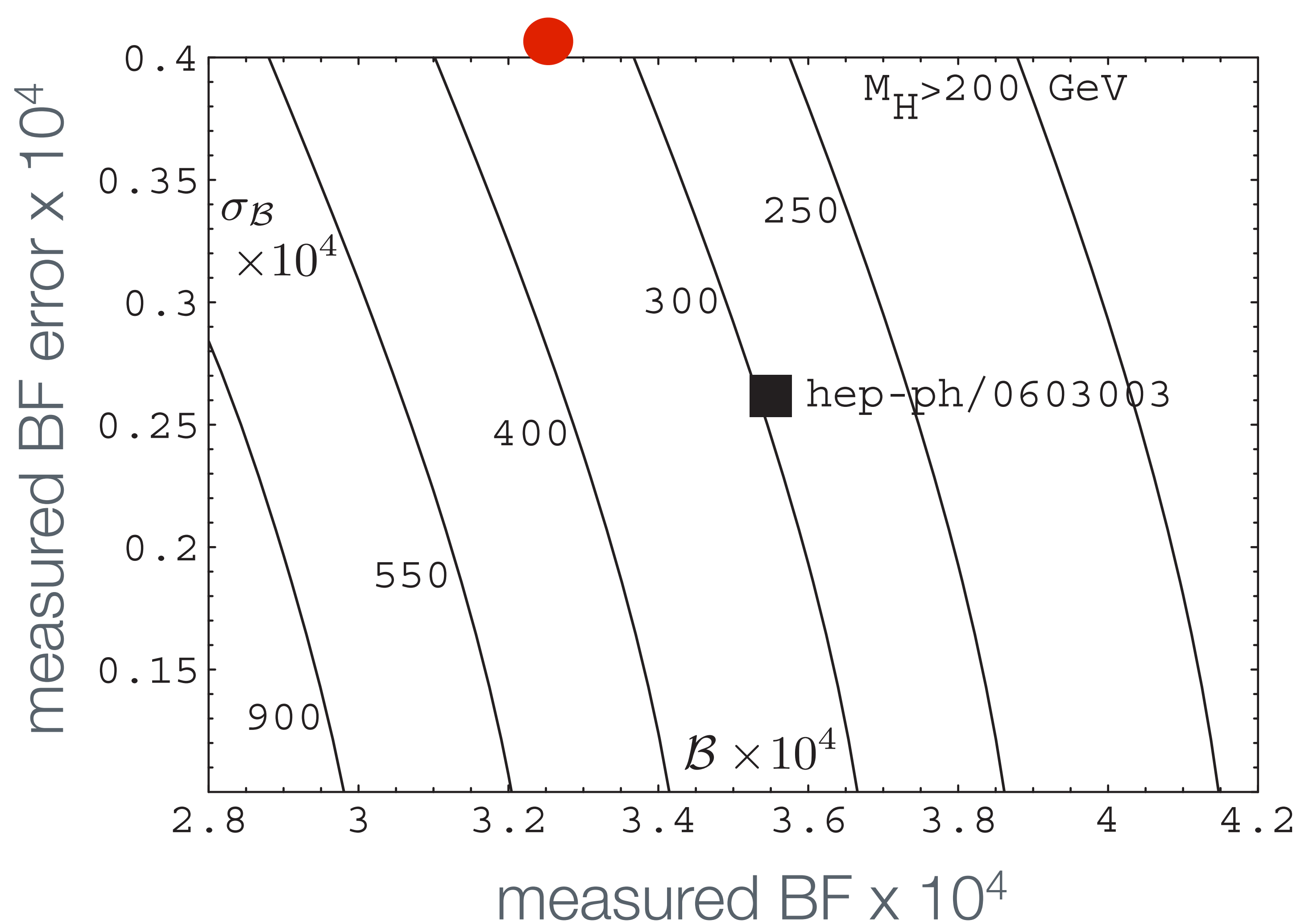
b→sγ in the 2HDM

Theoretical prediction,
Becher and Neubert, PRL 98, 022003 (2007)
$$BF(B \to X_s\gamma) = (2.98 \pm 0.26) \times 10^{-4}$$

Theoretical prediction,
Misiak et al, PRL 98, 022002 (2007)
$$BF(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

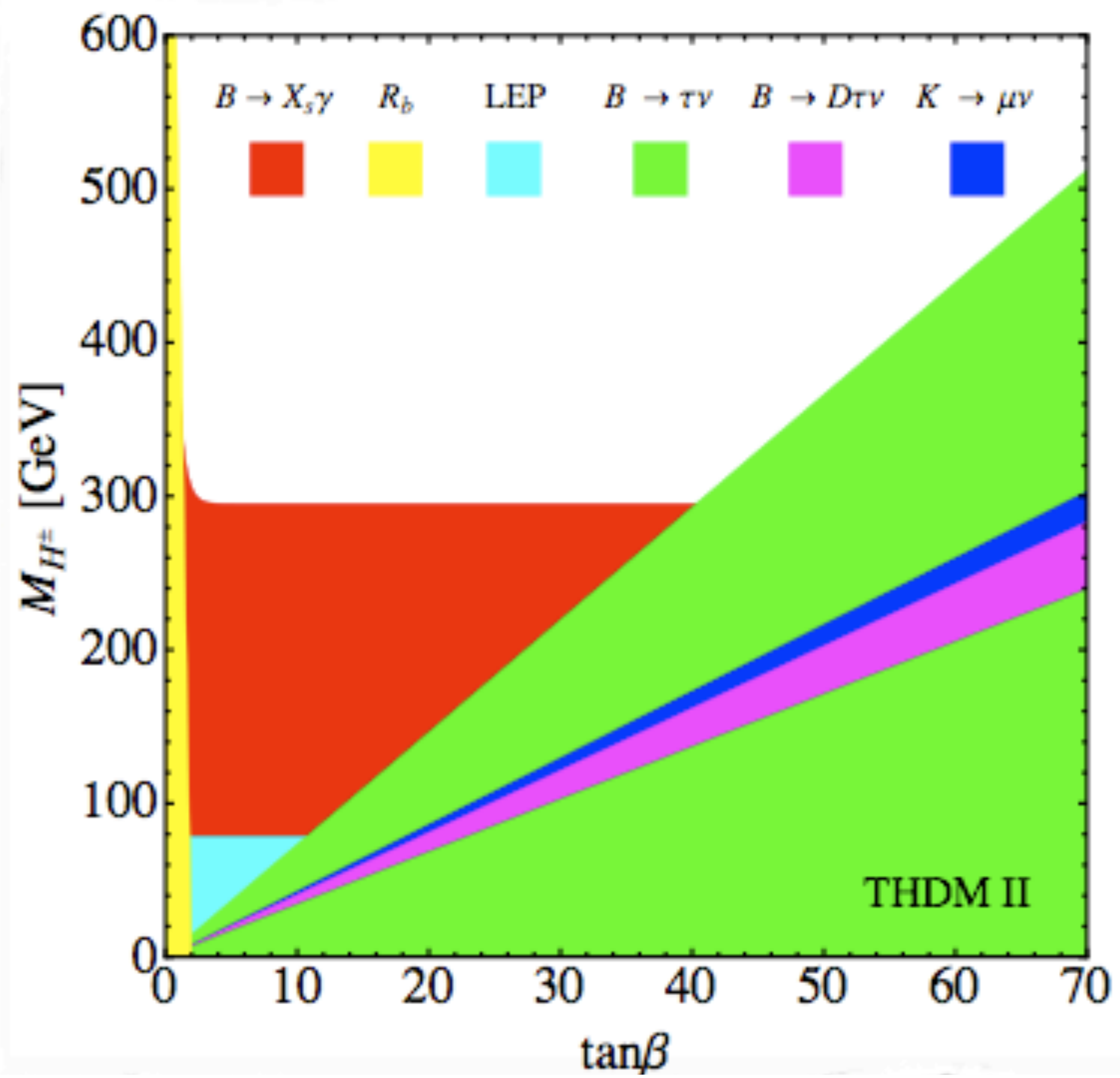
Barberio *et al*, HFAG, hep-ex/0603003
$$BF(B \to X_s\gamma) = (3.55 \pm 0.24^{+0.09}_{-0.1} \pm 0.02) \times 10^{-4}$$

Belle (prelim, Mor EW 08)
$$BF(B \to X_s\gamma) = (3.31 \pm 0.16 \pm 0.37 \pm 0.01) \times 10^{-4}$$

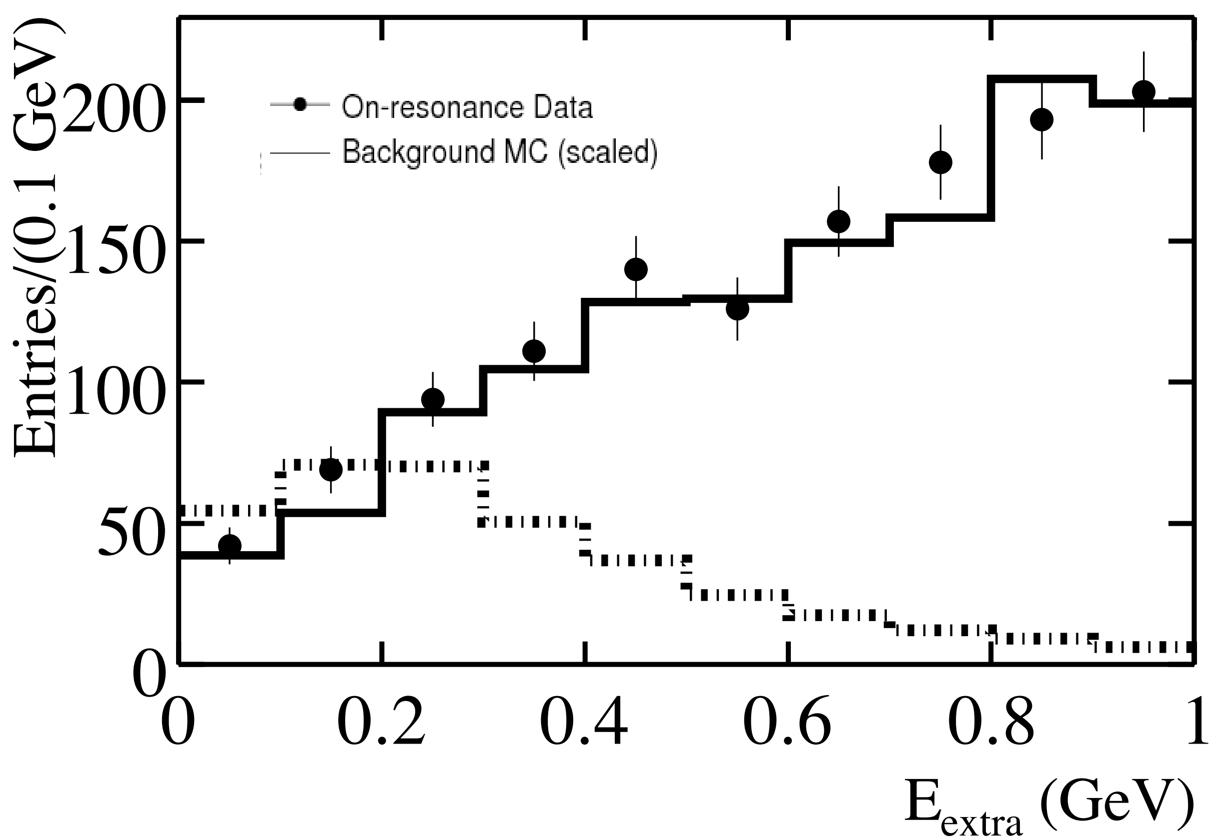


$B \to \tau\nu$, $B \to D^{(*)}\tau\nu$ and $b \to s\gamma$

- Moriond EW '08, Haisch

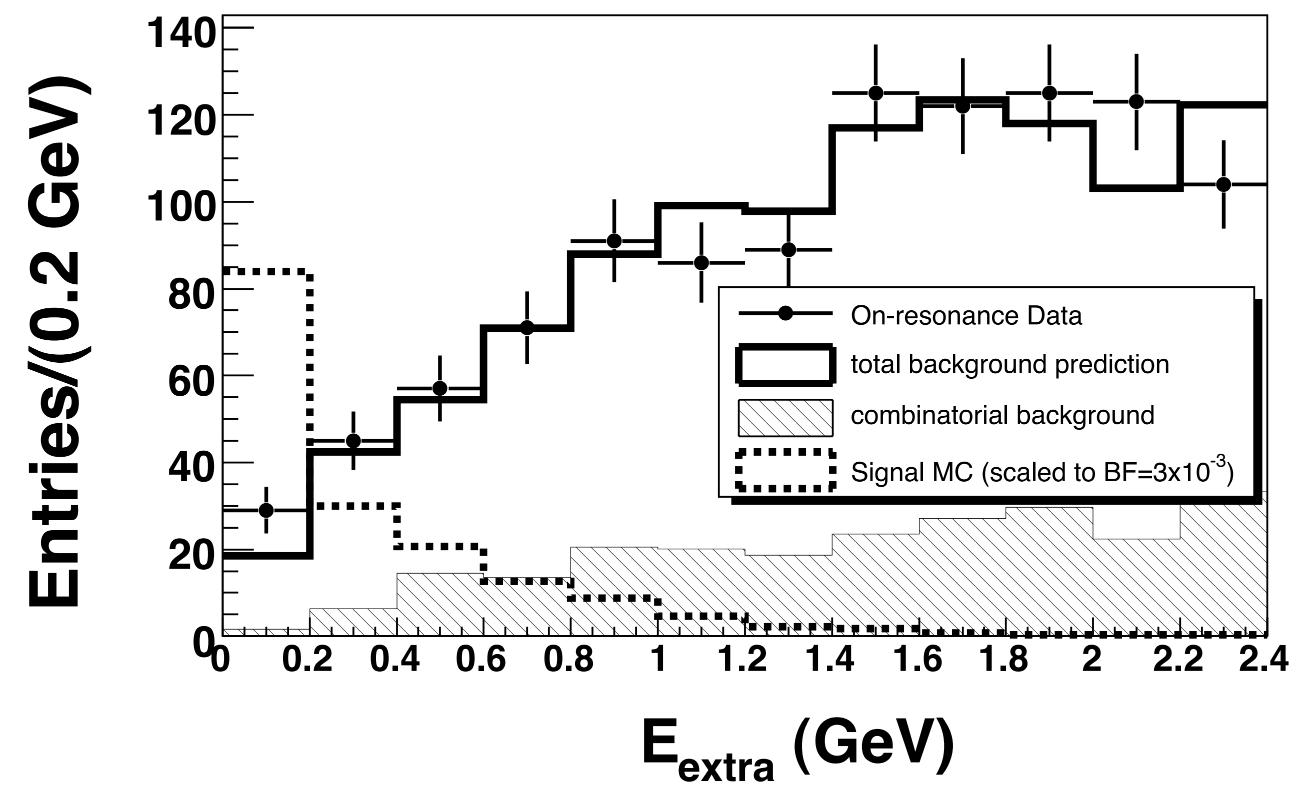


$B \rightarrow \tau\nu$: E_{extra} in Data and MC



PRD 76, 052002 (2007)

semileptonic tag



PRD-RC 77, 011107(2008)

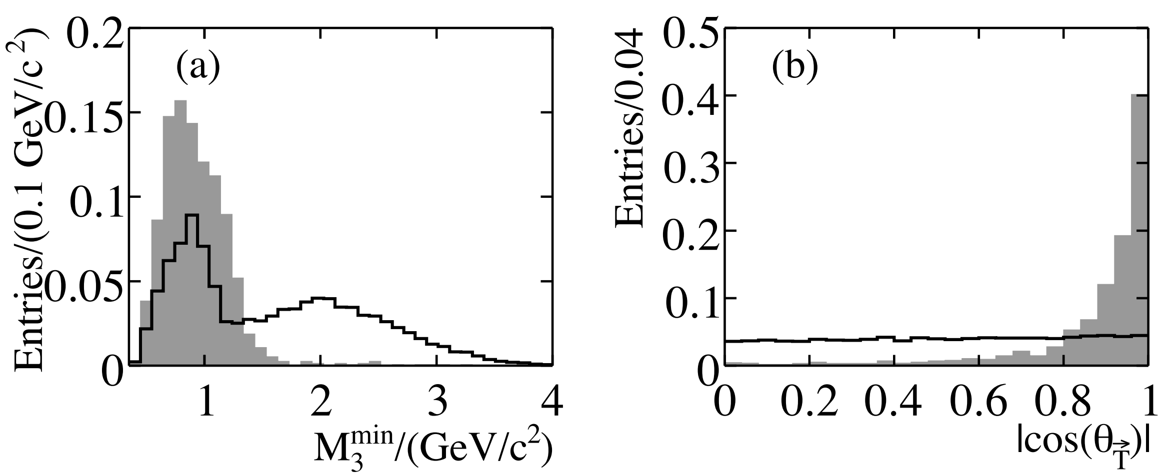
hadronic tag

B→τν: Selection (Tables)

SL Tag

mode	e^+	μ^+	π^+	$\pi^+\pi^0$
$M_{\rm miss}(\rm GeV/c^2)$	[4.6, 6.7]	[3.2, 6.1]	≥ 1.6	≤ 4.6
$p^*_{\rm signal}(\rm GeV/c)$	≤ 1.5	–	≥ 1.6	≥ 1.7
$R_{\rm cont}$	[2.78, 4.0]	> 2.74	> 2.84	> 2.94
$E_{\rm extra}(\rm GeV)$	< 0.31	< 0.26	< 0.48	< 0.25
Efficiency (%)	4.2 ± 0.1	2.4 ± 0.1	4.9 ± 0.1	1.2 ± 0.1

$$R_{\rm cont} \equiv \sqrt{(3.7 - |\cos\theta_{\vec{T}}|)^2 + (M_3^{\rm min}/(\rm GeV/c^2) - 0.75)^2}.$$



Had Tag

Variable	e^+	μ^+	π^+	$\pi^+\pi^0$
$E_{\rm extra}$ (GeV)	< 0.160	< 0.100	< 0.230	< 0.290
π^0 multiplicity	0	0	≤ 2	–
Track multiplicity	1	1	≤ 2	1
$\lvert\cos\theta^*_{TB}\rvert$	≤ 0.9	≤ 0.9	≤ 0.7	≤ 0.7
$p^*_{\rm trk}$(GeV/c)	< 1.25	< 1.85	> 1.5	–
$\cos\theta^*_{\rm miss}$	< 0.9	–	< 0.5	< 0.55
$p^*_{\pi^+\pi^0}$(GeV/c)	–	–	–	> 1.5
x_ρ	–	–	–	< 2.0
E_{π^0} (GeV)	–	–	–	> 0.250

$B \to \tau\nu$: Background predictions

SL Tag

signal mode	Background Prediction e^+	μ^+	π^+	$\pi^+\pi^0$
E_{extra} sideband	44.3±5.2	39.8±4.4	120.3±10.2	17.3±3.3
D^0 sideband	44.2±6.4	42.8±6.0	113.4±11.6	16.3±4.5

τ decay mode	Expected background events	Observed events in on-resonance data
$\tau^+ \to e^+\nu\overline{\nu}$	44.3 ± 5.2	59
$\tau^+ \to \mu^+\nu\overline{\nu}$	39.8 ± 4.4	43
$\tau^+ \to \pi^+\overline{\nu}$	120.3 ± 10.2	125
$\tau^+ \to \pi^+\pi^0\overline{\nu}$	17.3 ± 3.3	18
All modes	221.7 ± 12.7	245

Had Tag

τ decay mode	Expected background	Observed
$\tau^+ \to e^+\nu\overline{\nu}$	1.47 ± 1.37	4
$\tau^+ \to \mu^+\nu\overline{\nu}$	1.78 ± 0.97	5
$\tau^+ \to \pi^+\overline{\nu}$	6.79 ± 2.11	10
$\tau^+ \to \pi^+\pi^0\overline{\nu}$	4.23 ± 1.39	5
All modes	14.27 ± 3.03	24