Rare Decay Searches at BaBar

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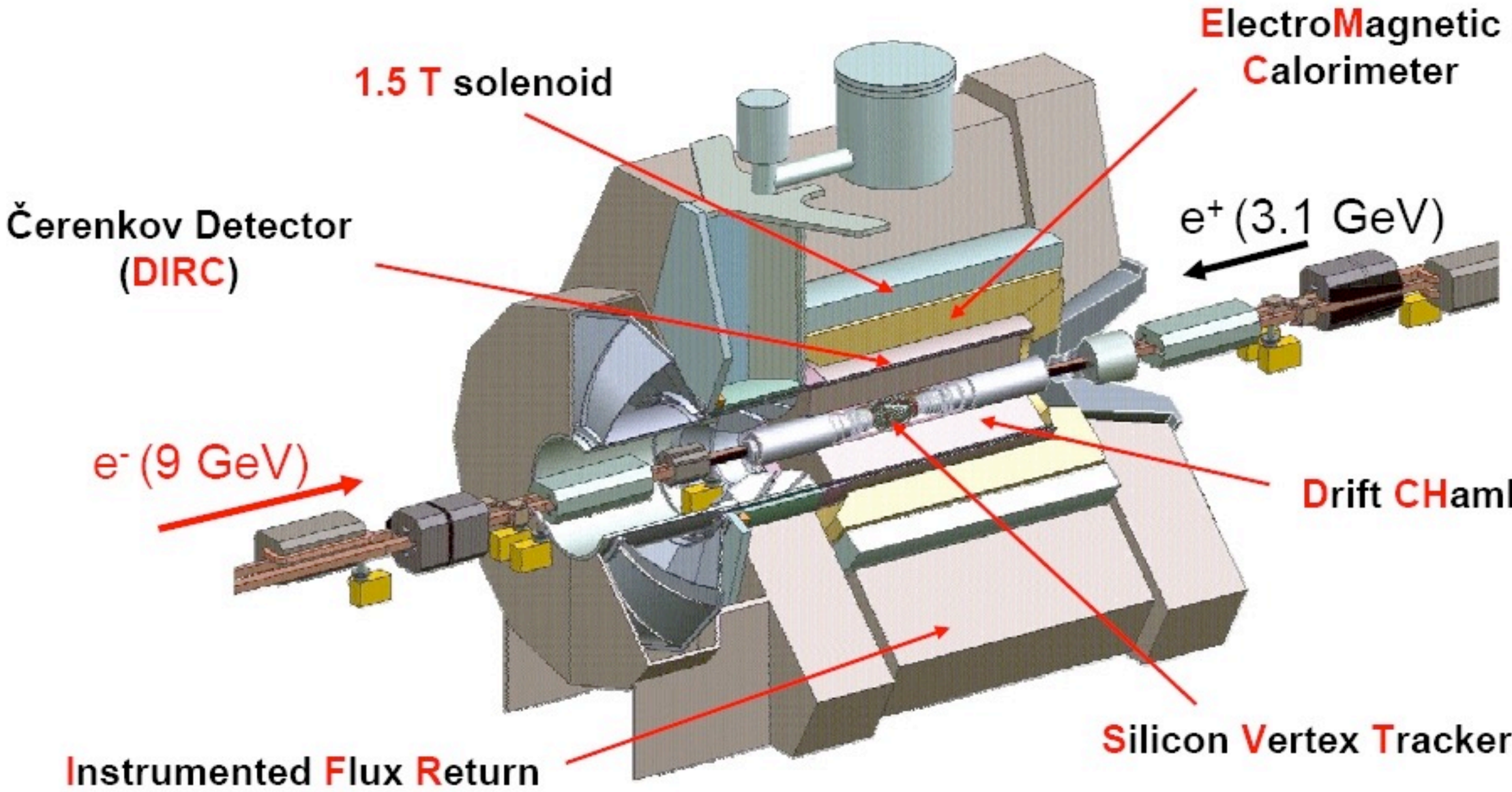
Outline

- BaBar Detector & Dataset
- B Physics
  - Rare Leptonic decays ($B \to \tau\nu$, $B \to K\nu\nu$, $B \to K\tau\tau$)
  - Very Rare decays ($B \to \gamma\gamma$)
  - $B_s \to Xl\nu$
- (Charm Physics-See Ryan White talk on thursday)
  - Search for CP violation in D ($D^+ \to K_S\pi^+$)
  - Very Rare decays ($D \to \gamma\gamma$)

The BaBar Detector



Dataset

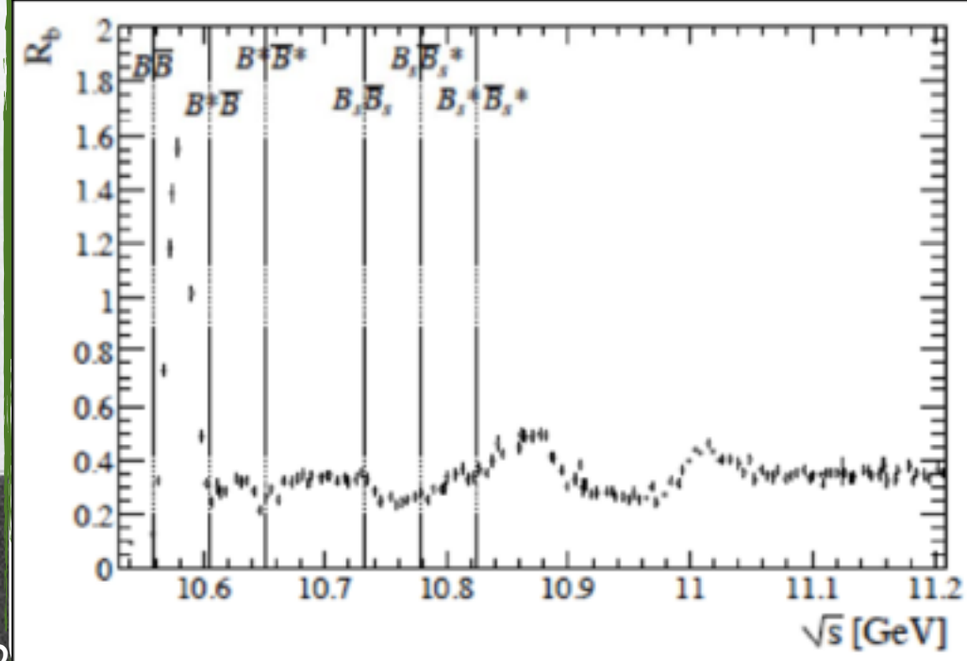
530 fb^{-1} recorded in the 9-years of operations

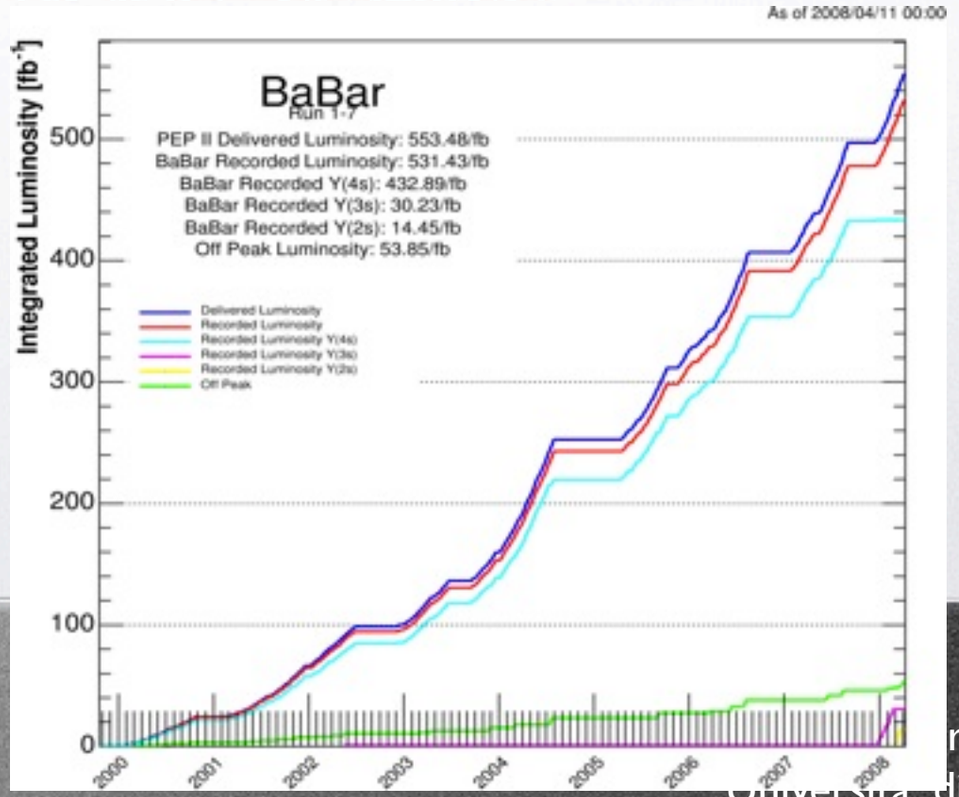
sample	fb^{-1}
$\Upsilon(4S)$	430
$\Upsilon(3S)$	30.2
$\Upsilon(2S)$	14.5
Off-Υ(nS)	54

~470x10^6 BB pairs but also:
7x(Belle + Cleo) $\Upsilon(3S)$
0.5x(Belle +Cleo) $\Upsilon(2S)$

Not Only BB pairs:
690M cc pairs
500M $\tau\tau$ pairs

~4fb^{-1} collected above $\Upsilon(4S)$





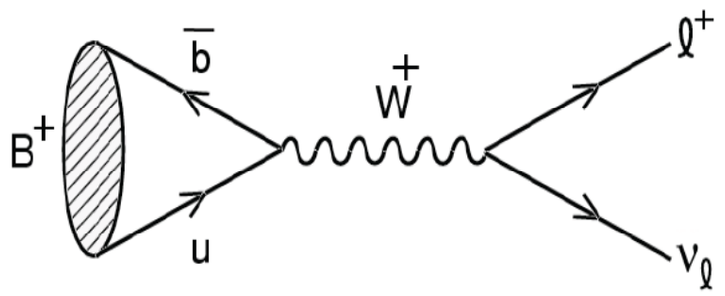
$B^+ \to \tau^+ \nu$: motivation

Powerful probe for NP: sensitive to Charged Higgs

$$B_{NP} = B_{SM}\left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

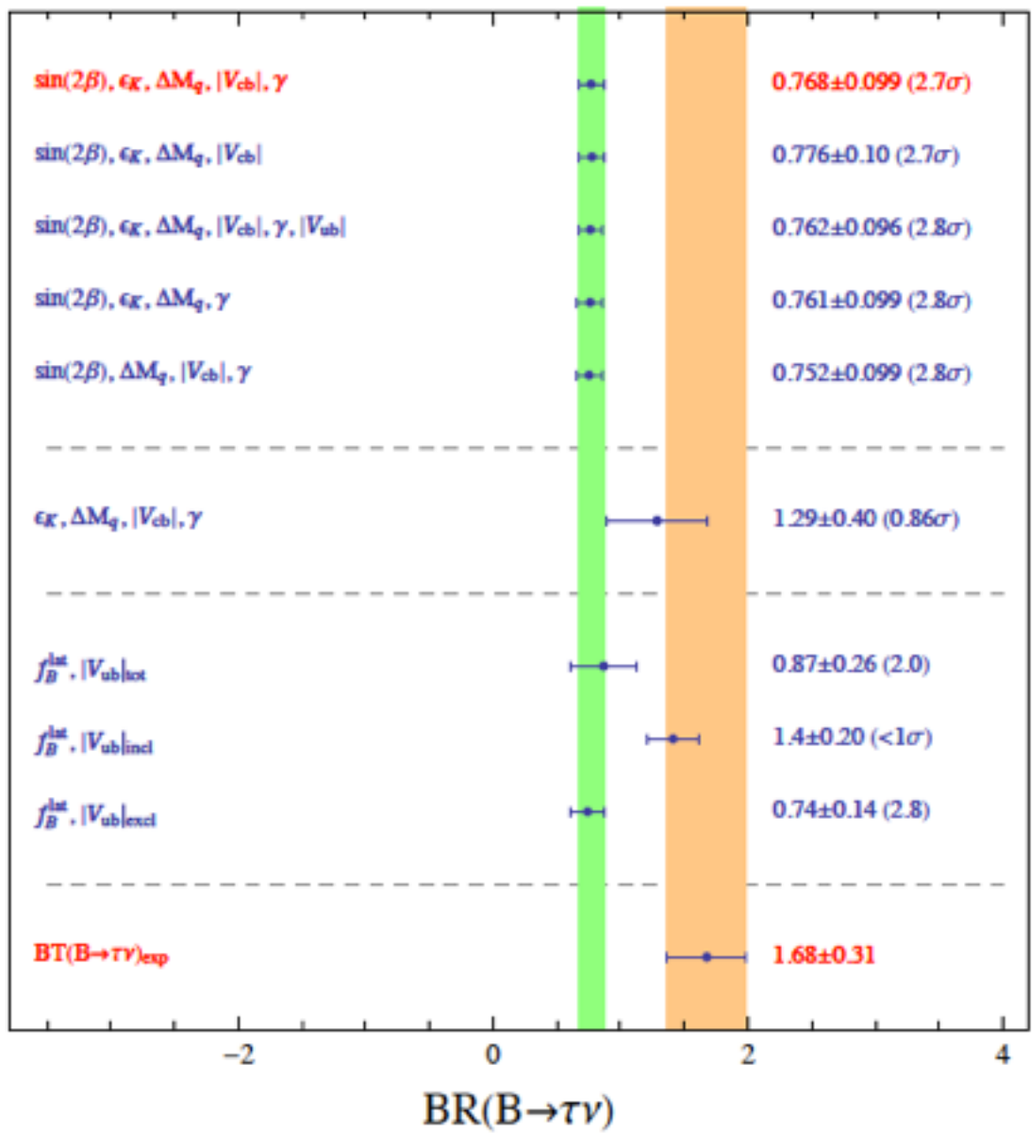
Helicity suppression give larger SM BF for taus:

$$B(B^+ \to \tau^+ \nu) \sim 1 \times 10^{-4}$$
$$B(B^+ \to \mu^+ \nu) \sim 4 \times 10^{-7}$$
$$B(B^+ \to e^+ \nu) \sim 1 \times 10^{-12}$$



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

SM BR depends on inputs but of O(10^{-4})



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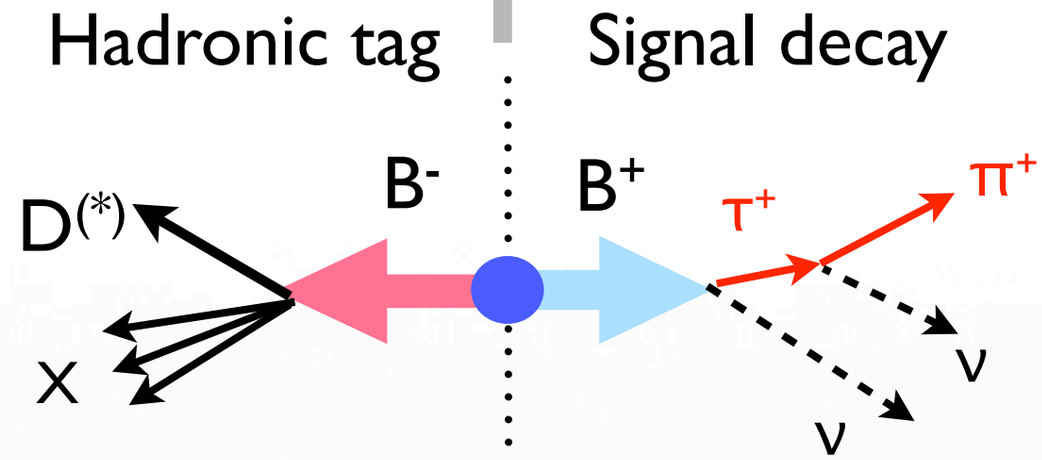
$B^+ \to \tau^+\nu$: Technique

- Few kinematic handles to reconstruct $B^+ \to \tau^+\nu$
- Reconstruct "other B" completely
  - Only one bachelor track associated to the τ decay should remain
  - look for signal in remaining tracks and clusters
- Reconstruct 4 τ decay modes:
  - **e**νν, **μ**νν, **π**ν, **ρ**ν ⇒ about 72% of total BF
- Key discriminating variable: ***Eextra***: *sum of neutral energy not associated with either reconstructed B meson*
- $B^+ \to \tau^+\nu$ will show an excess of events at Eextra ~ 0.



$$B^- \to D^{(*)0} X^-$$

$$\begin{aligned} D^0 &\to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+, \\ &\quad K^0_s\pi^0, K^0_s\pi^+\pi^-, K^0_s\pi^+\pi^-\pi^0 \\ &\quad K^+K^-, \pi^+\pi^- \\ D^{*0} &\to D^0\pi^0, D^0\gamma \end{aligned}$$

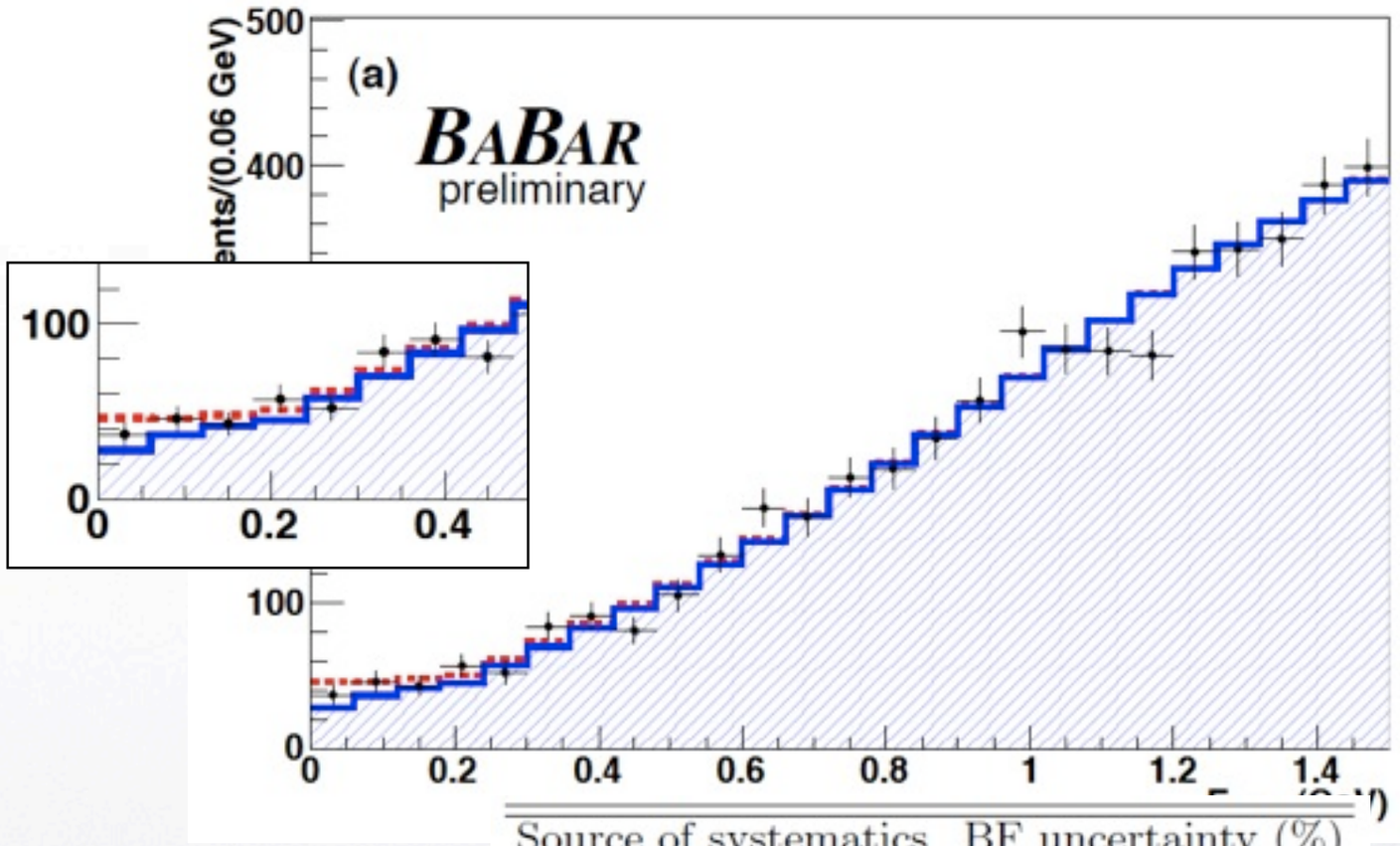
$$X = n\pi^\pm + mK + p\pi^0 + qK^0$$

$$n + m \leq 5, \quad m, p, q \leq 2$$

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

- Likelihood fit to *Eextra* variable to extract $B^+ \to \tau^+ \nu$ signal
- Signal template of *Eextra* from MC, corrected using data with both B completely reconstructed: 1 hadronic tag B 1 semileptonic or hadronic B
- Background templates:
  - combinatoric: m_{ES} sideband
  - peaking: from B^+B^- MC
- Fit yield: 69 ± 21 events (3.3σ)
- ***Preliminary branching fraction (Had tag only) :***

$$B(B^+ \to \tau^+ \nu_\tau) = (1.80^{+0.57}_{-0.54\ \mathrm{stat}} \pm 0.26_{\mathrm{syst}}) \times 10^{-4}$$

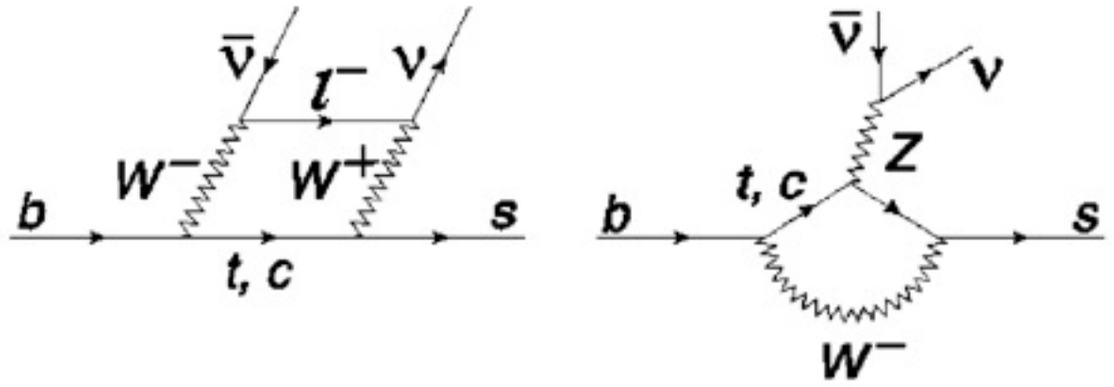


Source of systematics	BF uncertainty (%)
B counting	0.5
Tag B efficiency	5.0
Background PDF	12
Signal PDF	1.7
MC statistics	0.8
Electron identification	2.6
Muon identification	4.7
Kaon identification	0.4
Tracking	1.4
Total	14

Combined results (10^{-4})	
BaBar	1.76±0.49
Belle	1.54±0.48
HFAG	1.64±0.34

$B \to K\nu\nu$: motivation

- $b \to s$ FCNC, analogous to $B \to K l^+ l^-$, and therefore sensitive to NP: unparticles, MSSM, universal extra dimensions, etc.
- Standard Model BF small ~ 3.8×10^{-6}
- NP models predict BF up to a factor of 10 larger

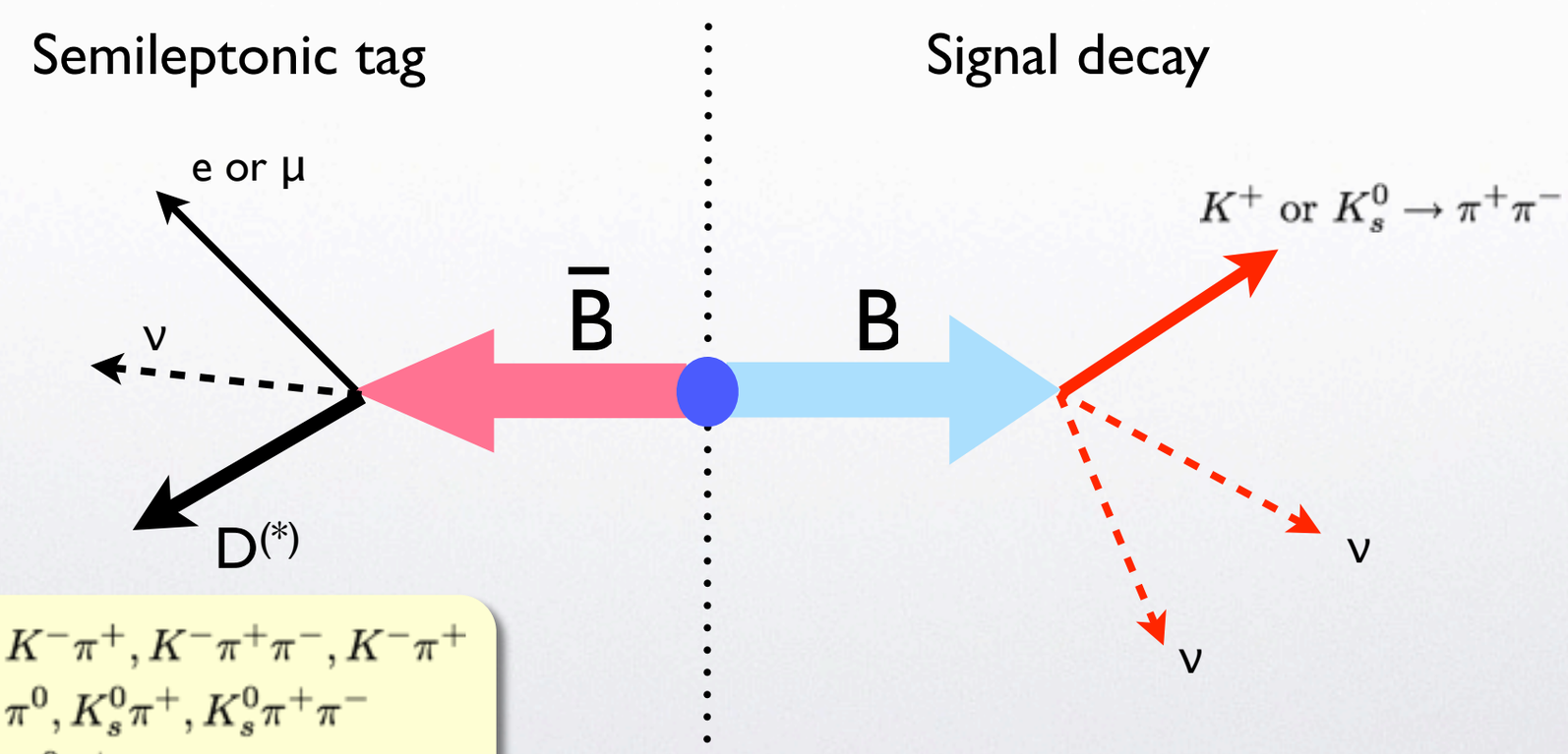


Previous measurements

Mode	Upper Limit (90% CL)	Experiment	Dataset (fb^{-1})	Reference
$B^+ \to K^+\nu\nu$	1.4×10^{-5}	Belle	492	PRL 99, 221802 (2007)
$B^+ \to K^+\nu\nu$	5.2×10^{-5}	BaBar	82	PRL 94, 101801 (2005)
$B^0 \to K^0\nu\nu$	1.6×10^{-4}	Belle	492	PRL 99, 221802 (2007)

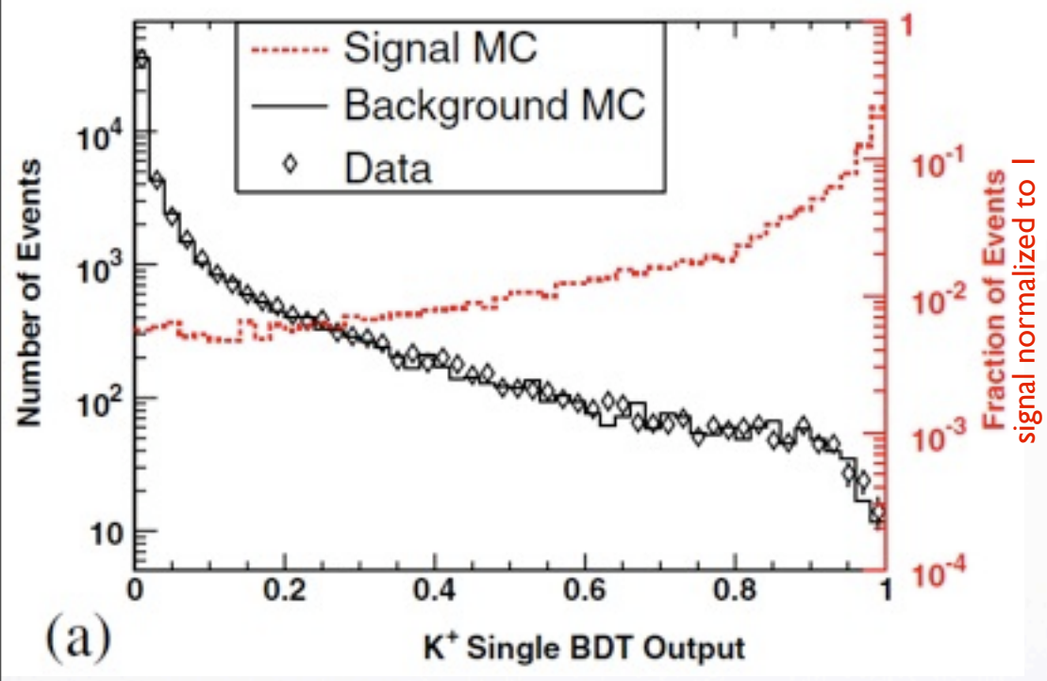
$B \to K\nu\nu$: Technique

- As for $B^+ \to \tau^+\nu$, few kinematical constraints on final state
  $\Rightarrow$ reconstruct "other" B in event in *semileptonic* B decay
- Look for signal decay among remaining particles of event



D	$\to$	$K^-\pi^+, K^-\pi^+\pi^-, K^-\pi^+ \pi^0, K^0_s\pi^+, K^0_s\pi^+\pi^-$
D^{*+}	$\to$	$D^0\pi^+$
D^{*0}	$\to$	$D^0\pi^0$

B→Kνν: Technique



- Suppress high remaining background using multivariate classifier: Bagged Decision Trees (BDT)
- Ensemble of BDTs trained on simulated signal and background events
- Trees use 26 (K^+) or 38 (K^0) variables relating to i) *missing energy*, ii) *event shape*, iii) *signal kinematics* and iv) *quality of reconstructed tag*
- Selection optimized for signal significance: $s/(s+b)^{1/2}$

Expected events

Mode	ϵ (in %)	N_{sgnl}	N_{bkgd}
K^+	0.16	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$
K^0_S	0.06	0.5 ± 0.1	$3.9 \pm 1.3 \pm 0.4$
low-q^2 K^+	0.24	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$
high-q^2 K^+	0.28	2.1 ± 0.3	$187 \pm 10 \pm 46$

B→Kνν: Results

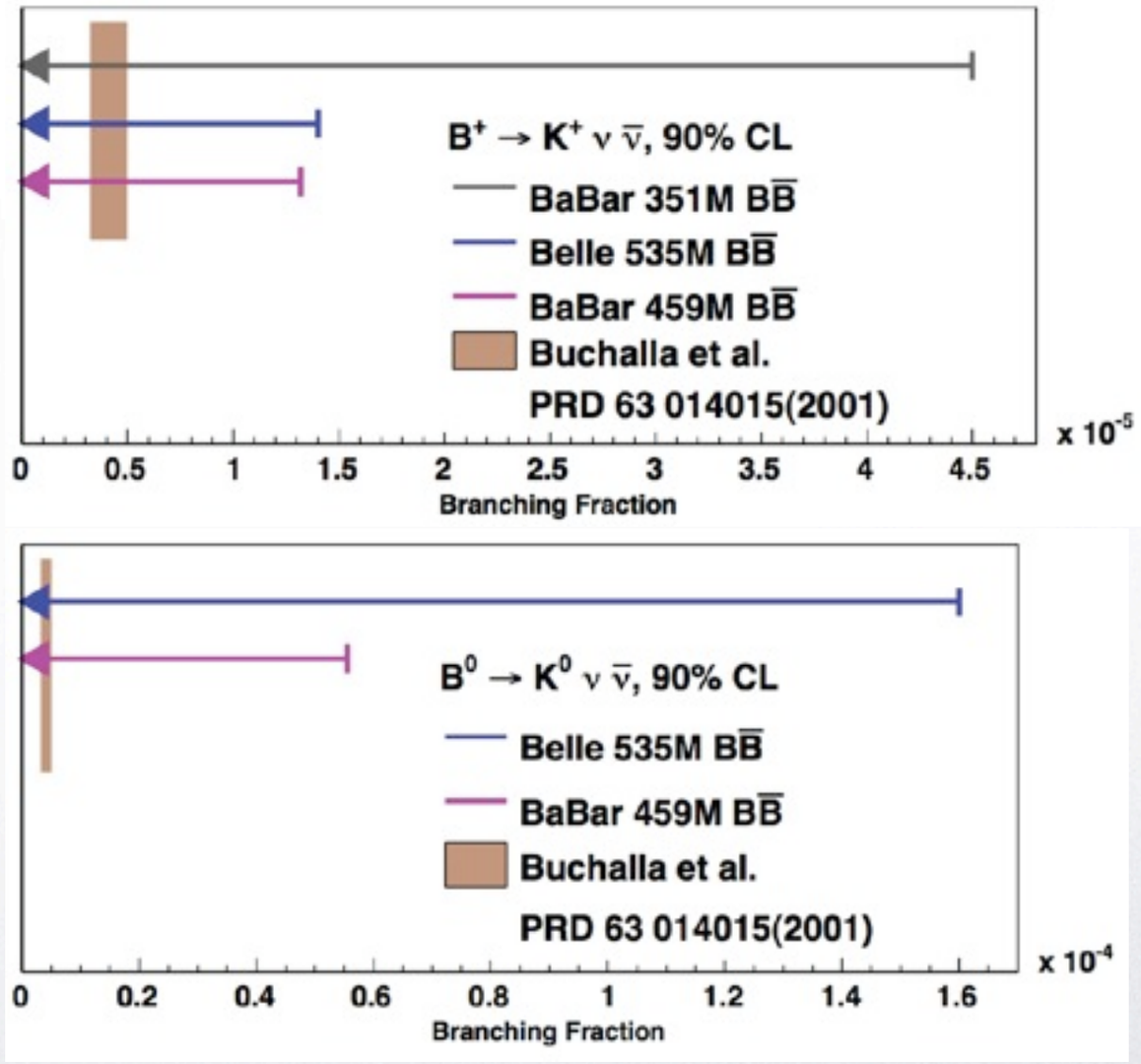
Observed events

N_{obs} - N_{BG}

Mode	N_{obs}	N_{excess}
K^+	$19.4^{+4.4}_{-4.4}$	$1.8^{+6.2}_{-5.1}$
K^0	$6.1^{+4.0}_{-2.2}$	$2.2^{+4.1}_{-2.8}$
low-q^2 K^+	$19.4^{+4.4}_{-4.4}$	$1.8^{+6.2}_{-5.1}$
high-q^2 K^+	164^{+13}_{-13}	-23^{+49}_{-48}

Upper limits

Mode	BF	90% CL	95% CL
	$\times 10^{-5}$	$\times 10^{-5}$	$\times 10^{-5}$
K^+	$0.2^{+0.8}_{-0.7}$	1.3	1.6
K^0	$1.7^{+3.1}_{-2.1}$	5.6	6.7
Comb. K^+, K^0	$0.5^{+0.7}_{-0.7}$	1.4	1.7
Low-q^2 K^+	$0.2^{+0.6}_{-0.5}$	0.9	1.1
High-q^2 K^+	$-1.8^{+3.8}_{-3.8}$	3.1	4.6



Best limits achieved to date

Phys. Rev. D ***82****, 112002 (2010)*

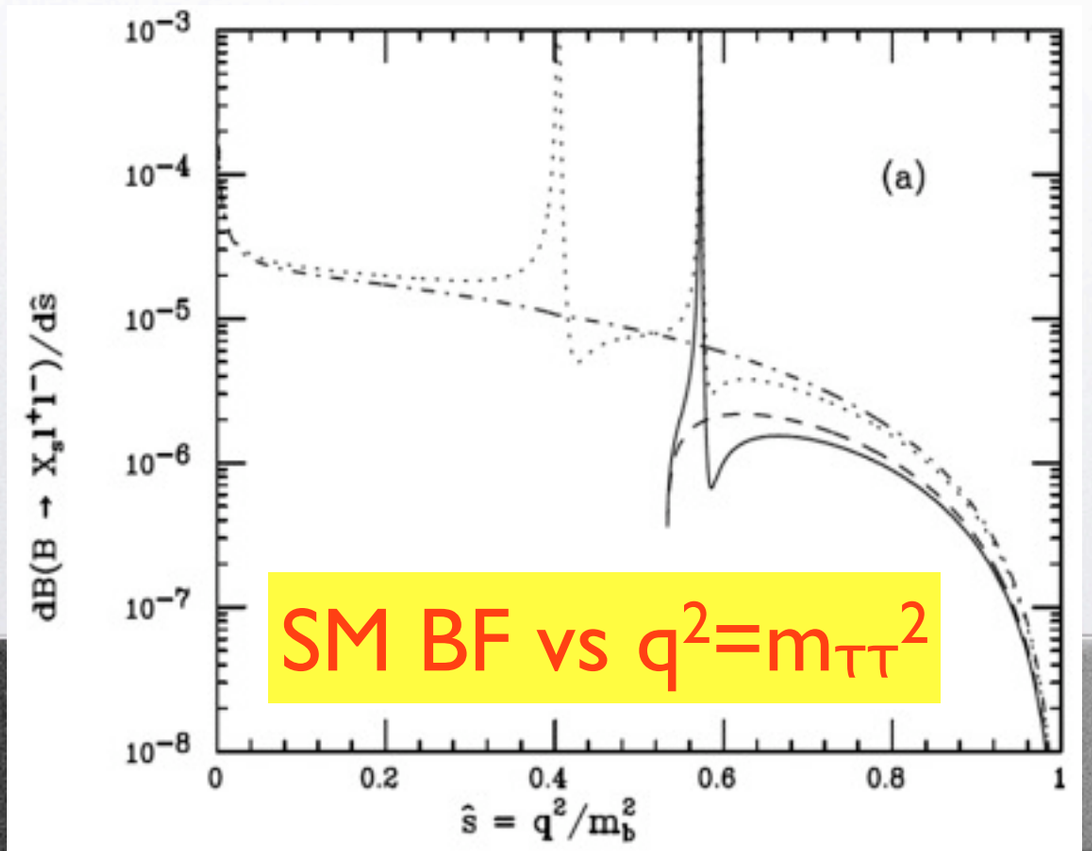
B→Kττ: Motivations

Similar to other B→Kll, SM BR smaller due to τ mass

$$s = m_{\tau\tau}^2/m_b^2 > 0.6 \rightarrow \mathcal{B} \sim 4.3 \times 10^{-7}$$

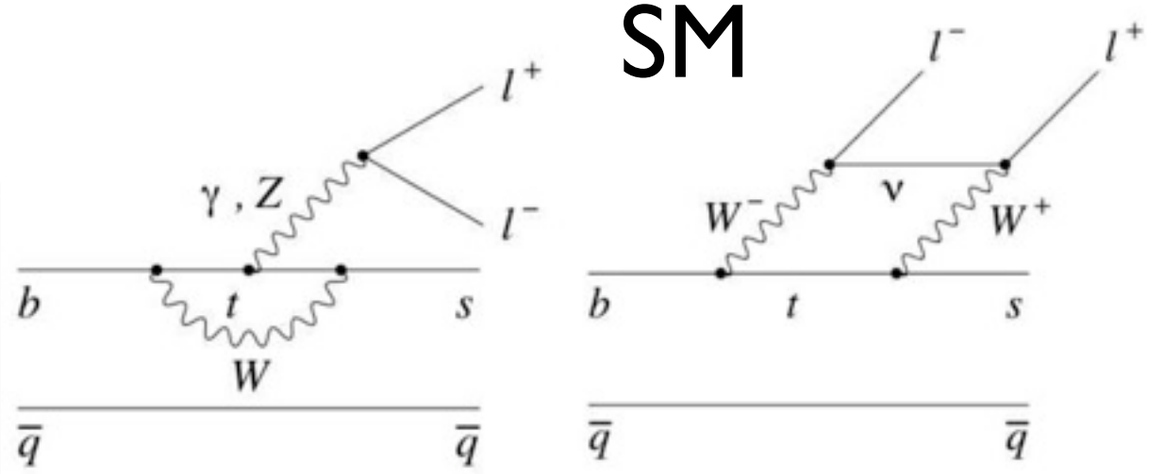
In some models BF can depend on lepton mass:

Phys. Rev. D70 (2004) $\mathcal{B} = \frac{m_\tau^2}{m_\mu^2} \cdot \mathcal{B}_{SM}$

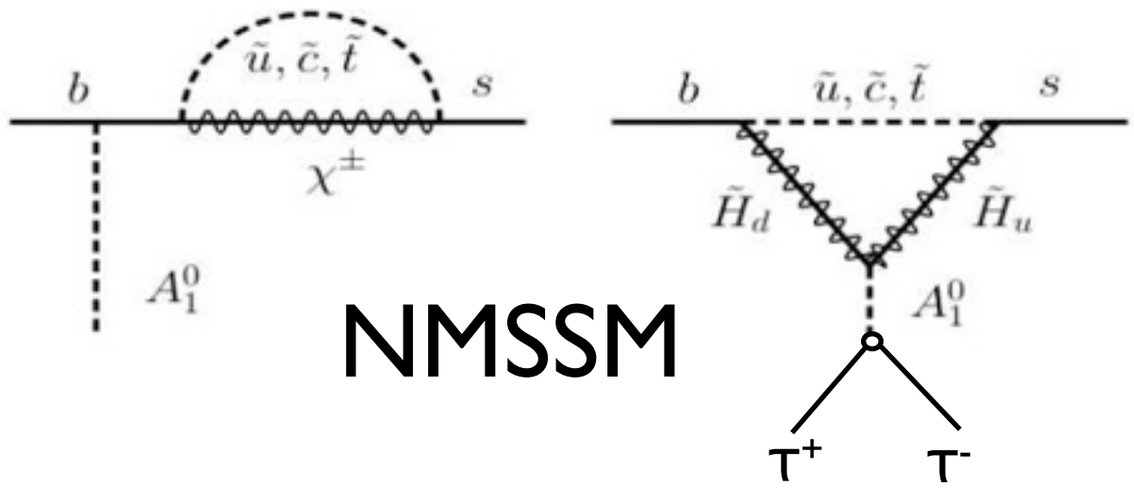


SM BF vs $q^2=m_{\tau\tau}^2$

SM



NMSSM



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B→Kττ: Techniques

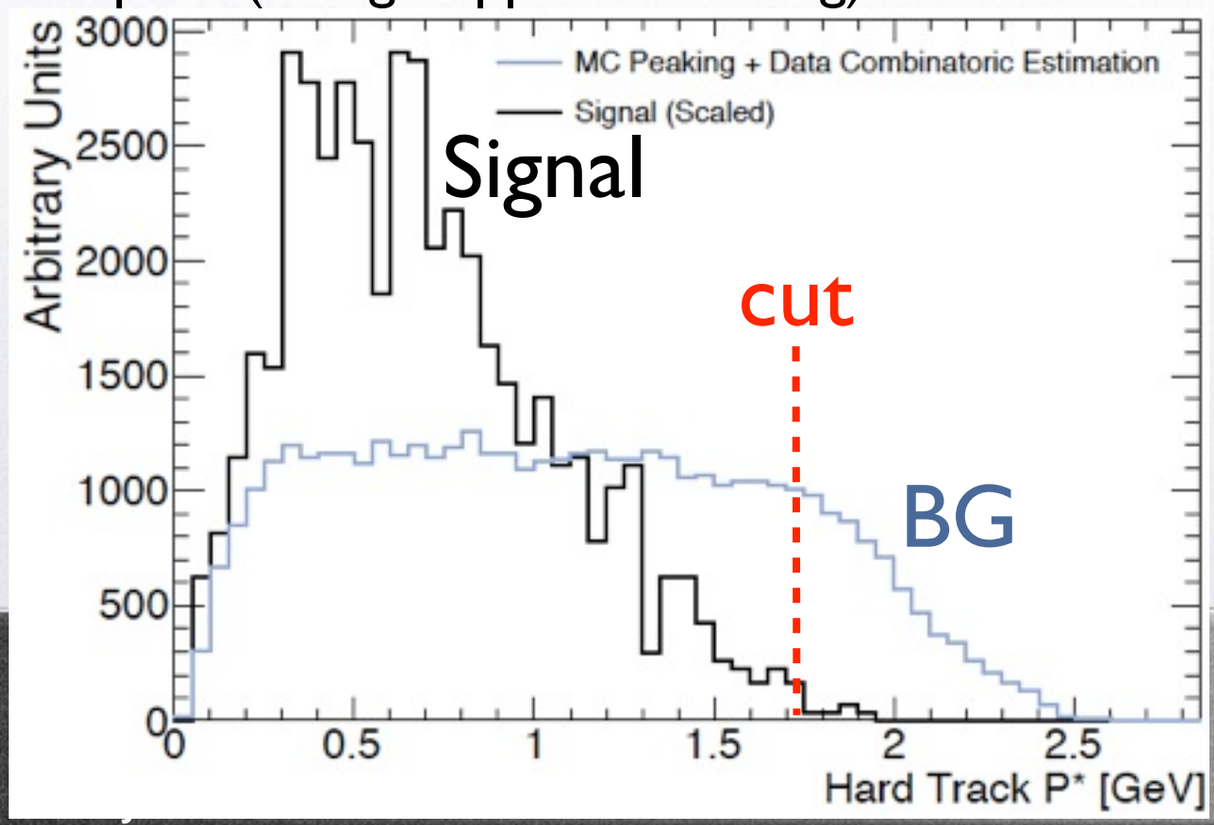
Hadronic tag on other B

Signal side: only 3 tracks, PID, thrust angle of sig/tag decays, missing Energy, E_{extra}, hard track momenta

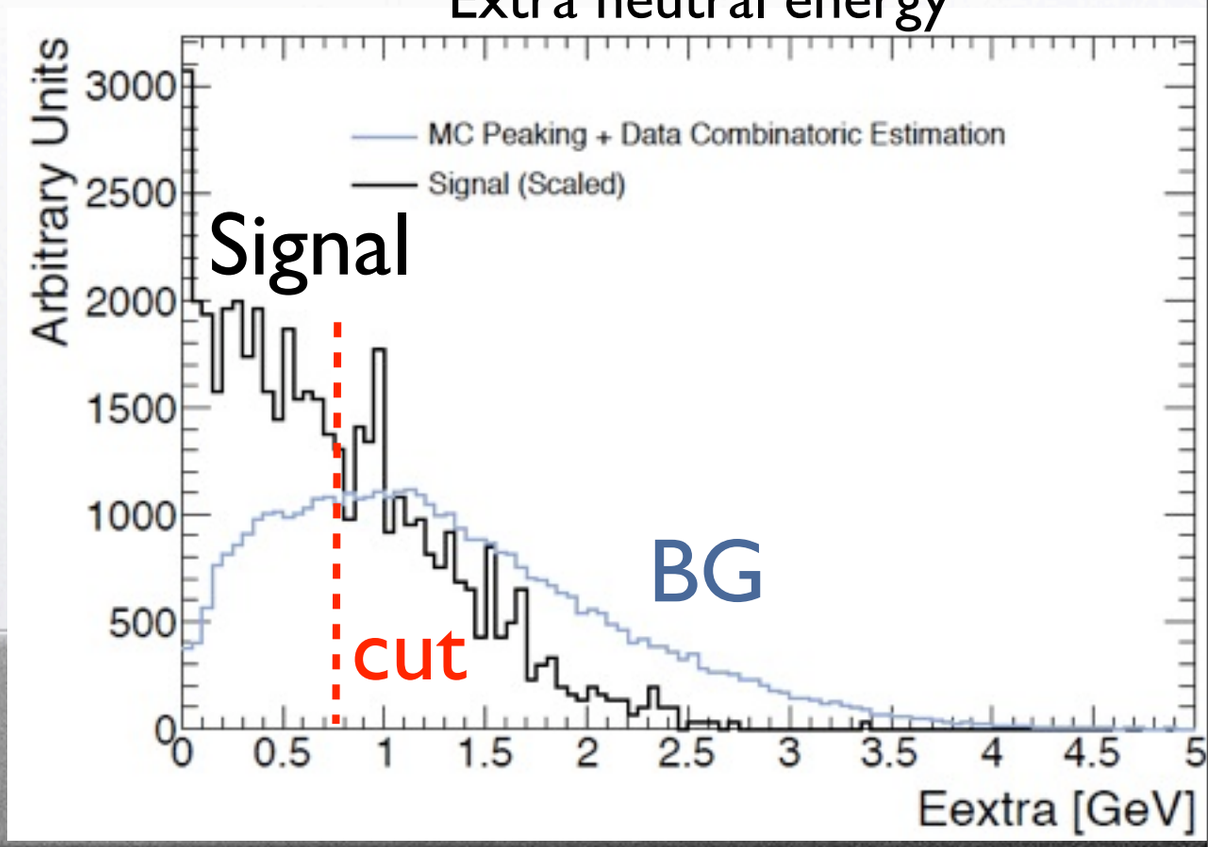
τ reconstructed in 1 prong decays
eνν, μνν, πν

Signal efficiency 4.45×10^{-4}

Lepton (charge opposite to Btag) momentum



Extra neutral energy

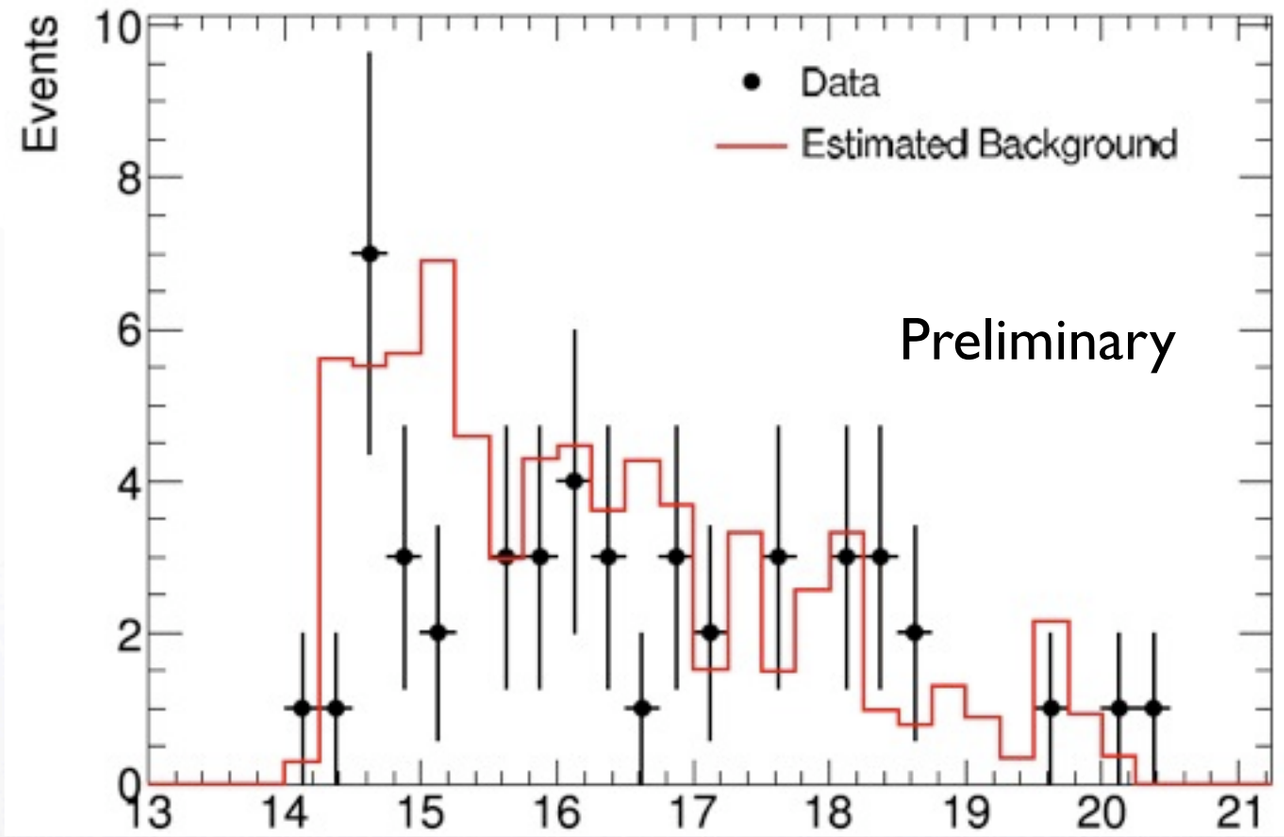


B→Kττ: Results

460 M BB pairs

- Expected background events: 65±7
- Observed events: 47
- No signal excess observed only UL set

- Main systematics
  - Signal efficiency: 15%
  - Bkg estimation: 17%

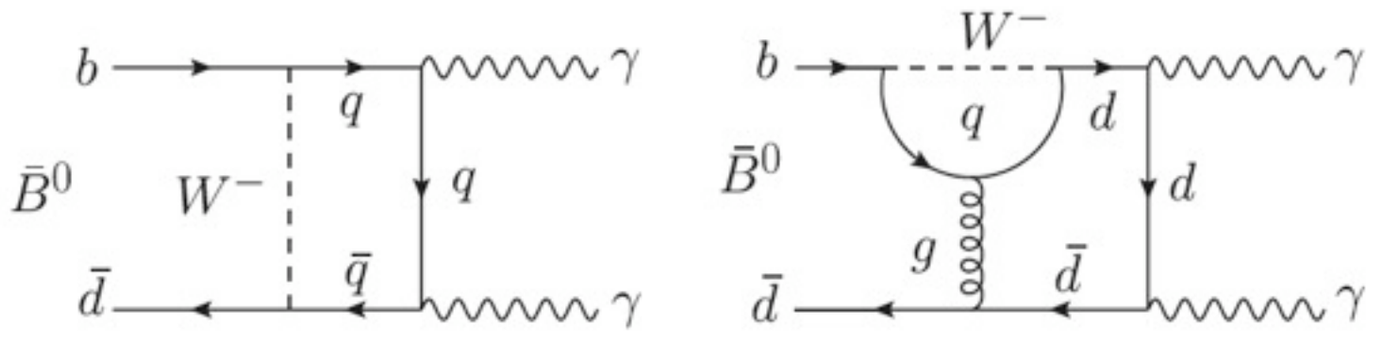


UL @90% CL: $B(B^+ \to K^+\tau^+\tau^-) < 3.3 \times 10^{-3}$

first experimental limit

B→γγ: Motivation

- Involves b→dγγ transition
  - small SM BF ~ $(3.1^{+6.4}_{-1.6}) \times 10^{-8}$
    JHEP 08 (2002) 054



- Can be enhanced by NP scenarios
  - extended Higgs sector: Aliev and Iltan, PRD 58, 095014 (1998)
  - SUSY with broken R-parity: Gemintern, Bar-Shalom and Eilam, PRD 70, 035008 (2004)

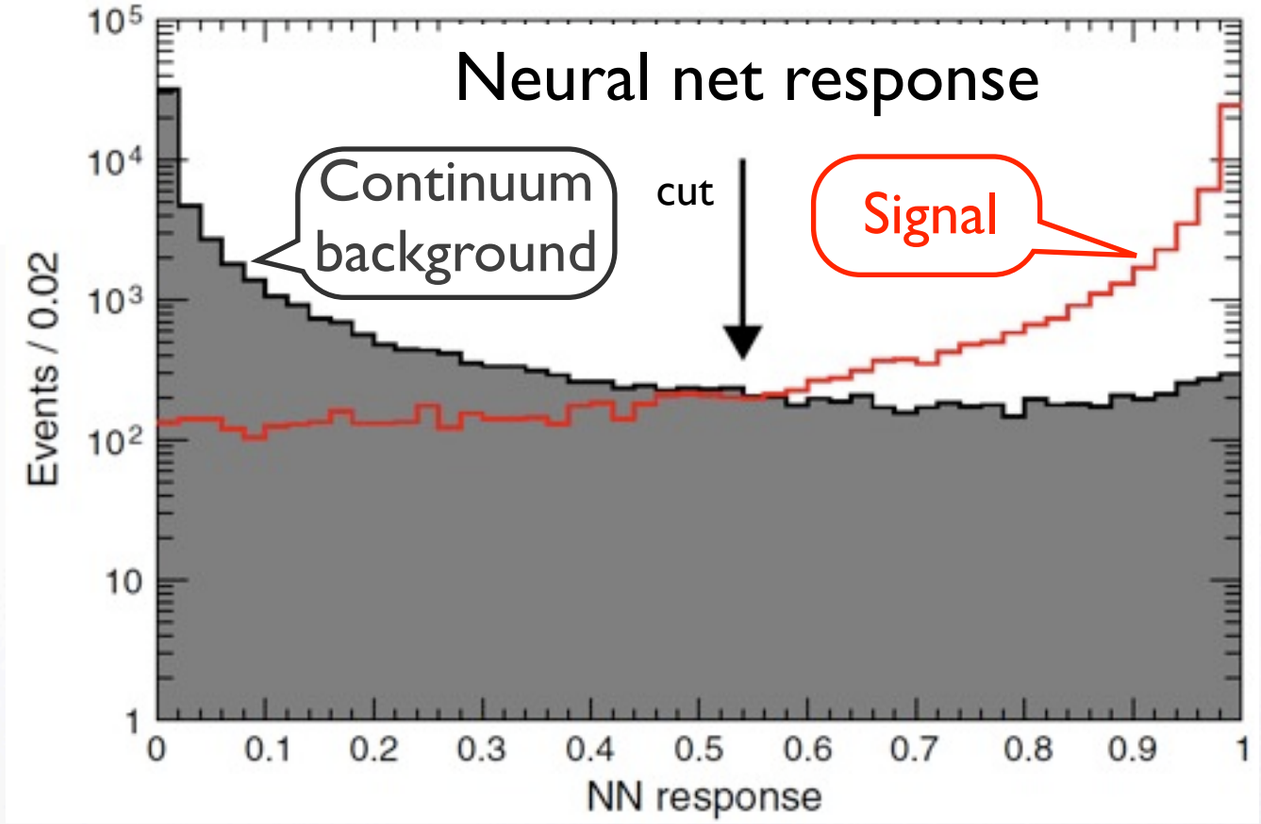
Best limit to date: $B(B^0 \to \gamma\gamma) < 6.2 \times 10^{-7}$ (90% CL)

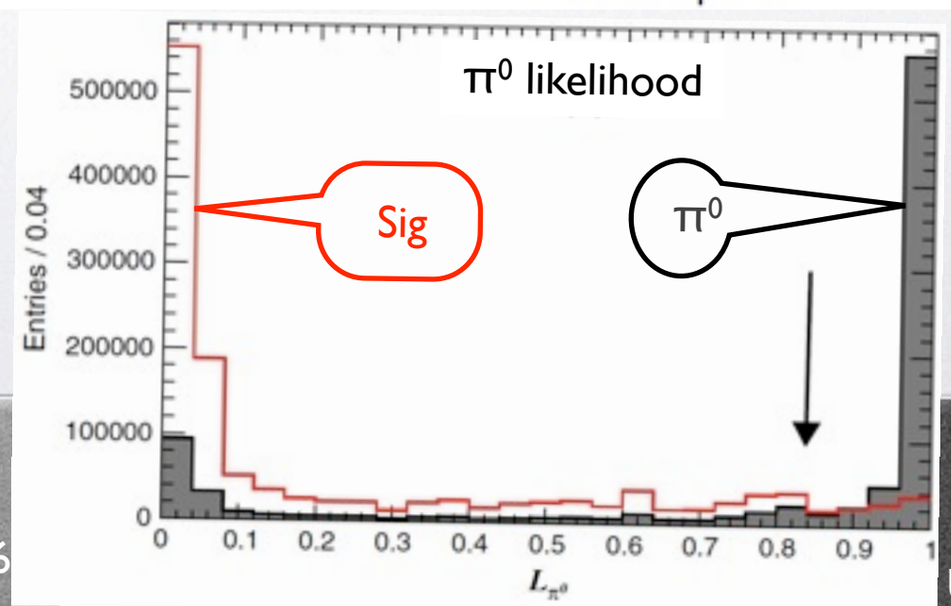
Belle, PRD 73, 051107 (2006)

B→γγ: Backgrounds

Background sources

- Decays of π^0 and η decays
  - reject with Likelihood ratio based on m(γγ') and $E_{\gamma'}$
- out-of-time Bhabha event overlap:
  - rejected with total energy and timing cuts
- Generic continuum events
  - Multivariate classifier (neural network) based on 19 input variables





Phys. Rev. D 83, 032006 (2011)

B→γγ: Results

467 M BB pairs

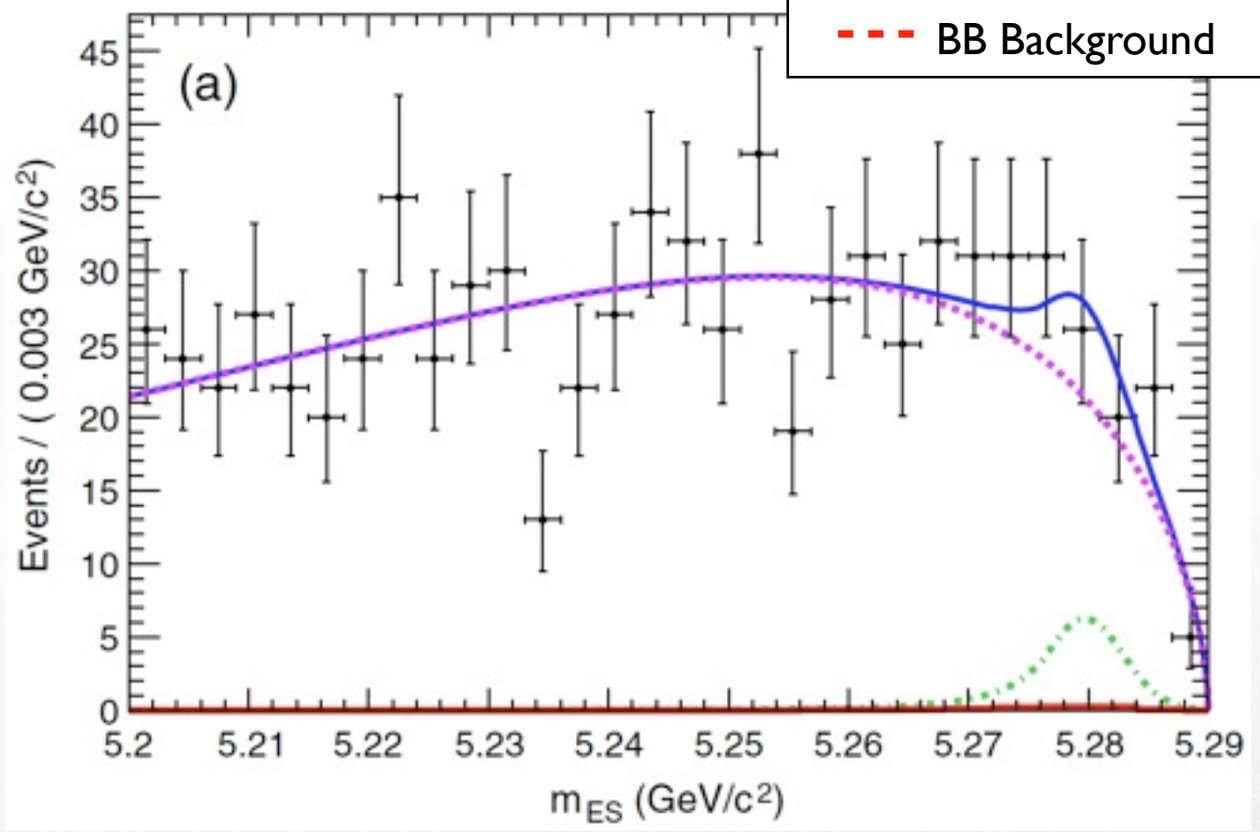
- 2-D likelihood fit to m_{ES} and ΔE variables
- Signal yield: $21.3^{+12.8}_{-11.8}$ events

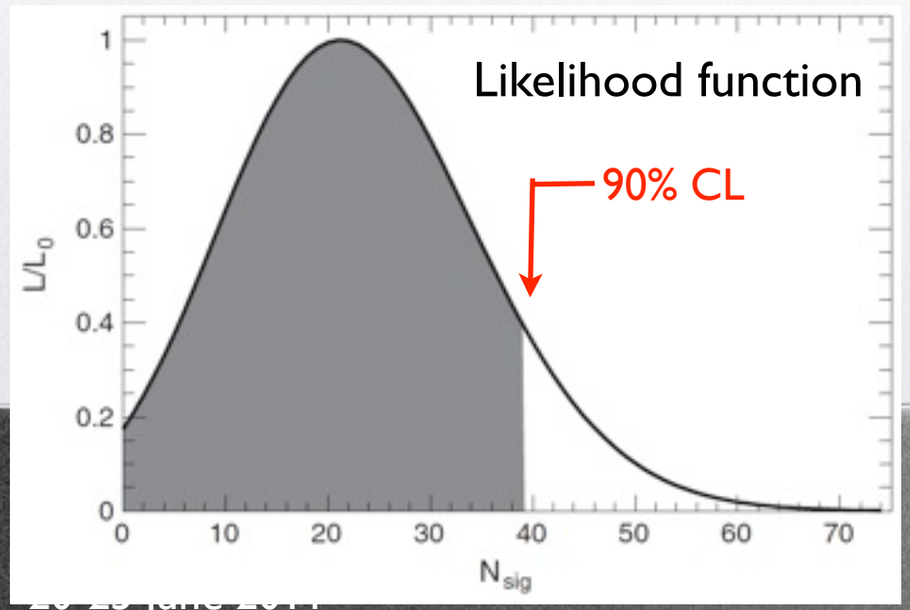
Measured branching fraction:

$B(B \to \gamma\gamma) = (1.7 \pm 1.1_{\rm stat} \pm 0.2_{\rm syst}) \times 10^{-7}$

(1.9σ significance)

$$m_{ES} = \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$$





Upper limit:

$B(B \to \gamma\gamma) < 3.3 \times 10^{-7}$ at 90% CL

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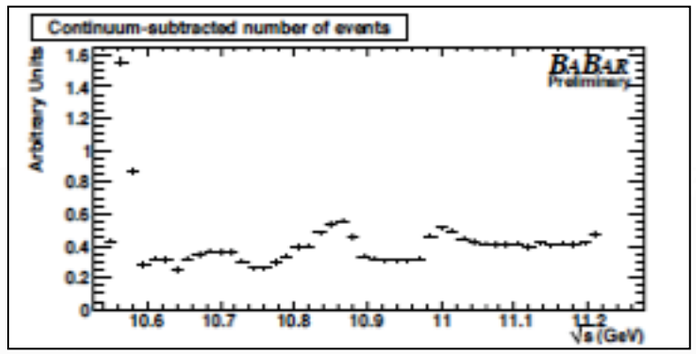
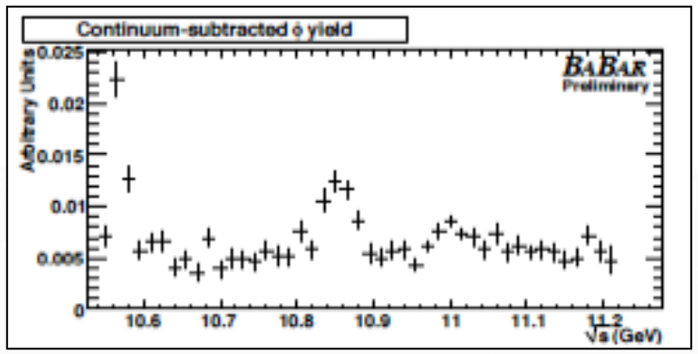
$B_s \rightarrow X l \nu$: Motivation

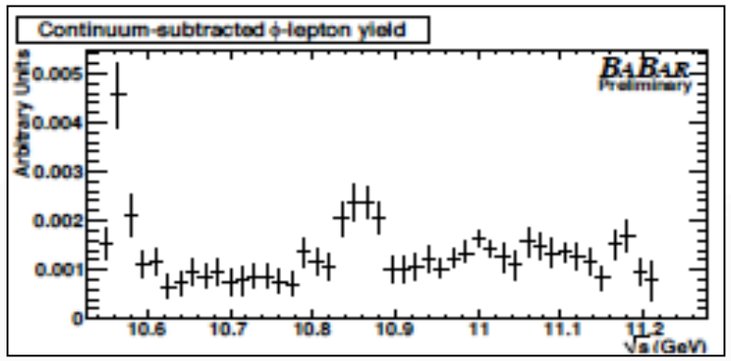
- Semileptonic Bs decays:
  - measurement from Belle (unpublished results) :
    $B(B_s \rightarrow X l \nu) = (10.2 \pm 0.8 \pm 0.9)\%$ (hep-ex:07102548, 2007)
  - LHCb measure ratios of semi-exclusive decays to total inclusive:
    $B(B_s \rightarrow (D_{s2}^*/D_{s1}) X l \nu) / B(B_s \rightarrow X l \nu)$ (Phys.Lett.B 698,14,2011)
- Exploit BaBar above-Y(4S) data: $(25.5 \pm 6.2) \times 10^3$ $B_s^{(*)}\underline{B}_s^{(*)}$ decays
- abundance of Φ meson in B_s final states (w.r.t to B) allow to measure size of B_s component
  - $B(B_s \rightarrow DsX) \times B(D_s \rightarrow \Phi X) \approx 15\%$
  - $B(B_d \rightarrow \Phi X) \approx 3.43\% \rightarrow$ measure f_s = # B_s produce above threshold / # $b\underline{b}$ events
  - measure $B_s \rightarrow X l \nu$ adding a high momentum lepton

$B_s \to X l \nu$: Results

Continuum subtracted yields







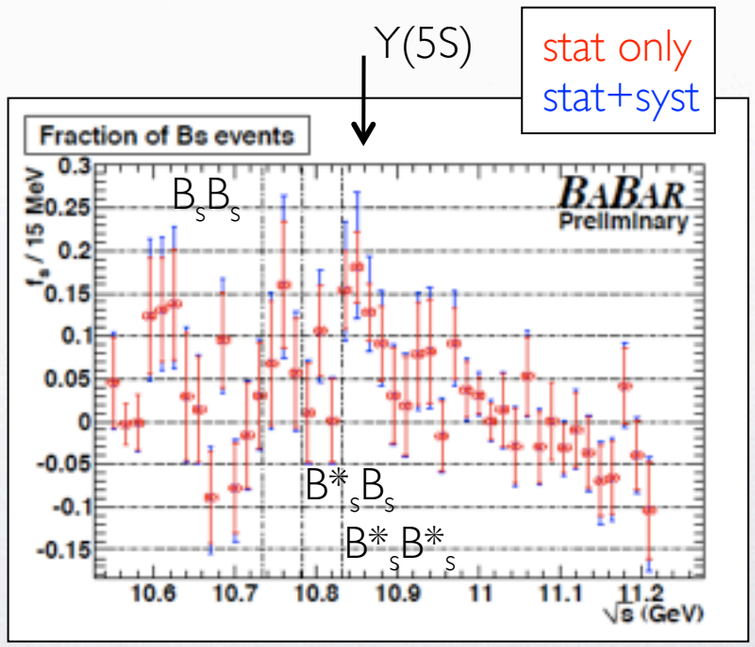
Semileptonic BF:

$$\mathcal{B}(B_s \to \ell \nu X) = (9.9^{+2.6}_{-2.1}(\text{stat})^{+1.3}_{-2.0}(\text{syst}))\%$$

fs : near Y(5S) peak consistency with on-peak results from

Belle : f_s = (19.3 ± 2.9) % (PRD76, 012002, 2007)

Cleo : f_s = (16.8 ± 2.6) % (PRD75, 012002, 2007)



Conclusion

- BaBar ended data-taking in 2008 but analysis still ongoing
- Many rare decays sensible to new Physics: BaBar high statistics consent to have great sensitivity to NP
- BaBar was not only a B-Factory, many new results on both B_d and B_s physics
- New results expected soon!

Thanks for your attention

Backup

D-Physics

D→γγ: Motivation

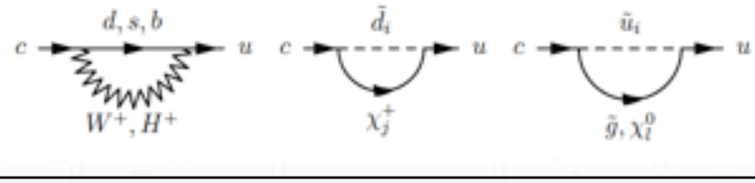
FCNC, GIM-suppressed charm loop diagrams:

SM dominated by long distance contributions (PRD 66,014009,2002)

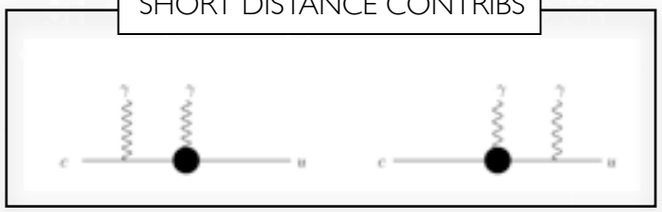
Looking for NP entering the loops

Mode	Value
$D^0 \to \gamma\gamma$ (SM,VMD)	$\approx (3.5\ ^{+4.0}_{-2.6}) \times 10^{-8}$
$D^0 \to \gamma\gamma$ (SM,HQχPT)	$(1.0 \pm 0.5) \times 10^{-8}$
$D^0 \to \gamma\gamma$ (MSSM)	6×10^{-6}
Experimental results	
Mode	Value
$D^0 \to \gamma\gamma$	$< 2.7 \times 10^{-5}$
$D^0 \to \pi^0\pi^0$	$(8.0 \pm 0.8) \times 10^{-4}$
$D^0 \to K^0_s\pi^0$	$(1.22 \pm 0.05) \times 10^{-2}$

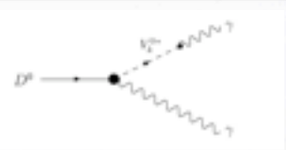
SM and MSSM LOOPS



SHORT DISTANCE CONTRIBS



LONG DISTANCE CONTRIBS



Strategy:

D^{*+} tag: D from $D^* \to \pi D$

Normalized to $D \to K\pi$

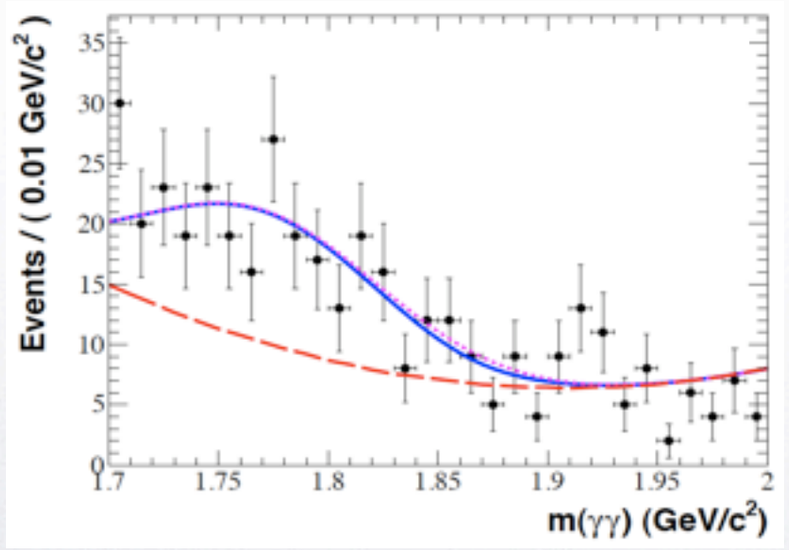
	$D^0 \to \gamma\gamma$	$D^0 \to \pi^0\pi^0$
selection efficiency		
signal	15.2 %	6.1%
normalization	12.0%	7.6%

Preliminary, 407.5 fb^{-1}

$D \to \gamma\gamma$: Results

Comb bkg
Comb bkg + $D^0 \to \pi^0\pi^0$
Comb bkg + $D^0 \to \pi^0\pi^0$ + signal
data

$D^0 \to \gamma\gamma$



N_{sig} = -6 ±15

$B(D^0 \to \gamma\gamma) < 2.4 \times 10^{-6}$

x 10 improvement wrt PDG

Main systematics from neutral pion veto

Systematic	$\sigma(D^0 \to \gamma\gamma)$ (%)
Tracking (K^0_S) and Vertexing	0.96
Photon Reconstruction	0.60
π^0 Veto	1.80
D^{*+} Fragmentation	0.02
Signal Shape	*
Background Shape	*
Cut selection	*
$D^0 \to K^0_s\pi^0$ Signal Shape	0.53
$D^0 \to K^0_s\pi^0$ Background Shape	0.01
$D^0 \to K^0_s\pi^0$ Cut selection	0.76
Total Systematic Uncertainty	*

CPV in D: Motivation

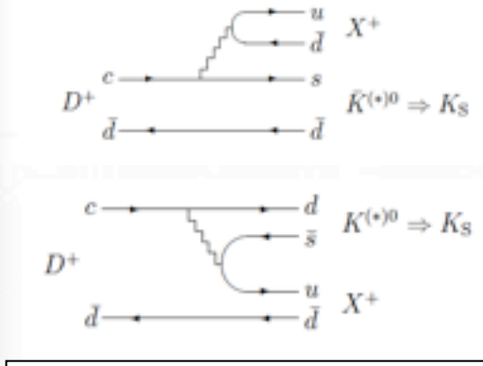
- Look for deviations from SM CPV prediction (i.e. coming from Charged Higgs or from different weak and strong phases (PLB450, 405,1999)
- CP Asymmetry

$$\mathcal{A}_{CP} = \frac{\Gamma(D^+ \to K_S\pi^+) - \Gamma(D^- \to K_S\pi^-)}{\Gamma(D^+ \to K_S\pi^+) + \Gamma(D^- \to K_S\pi^-)}$$

- SM prediction dominated by K^0K^0 mixing:

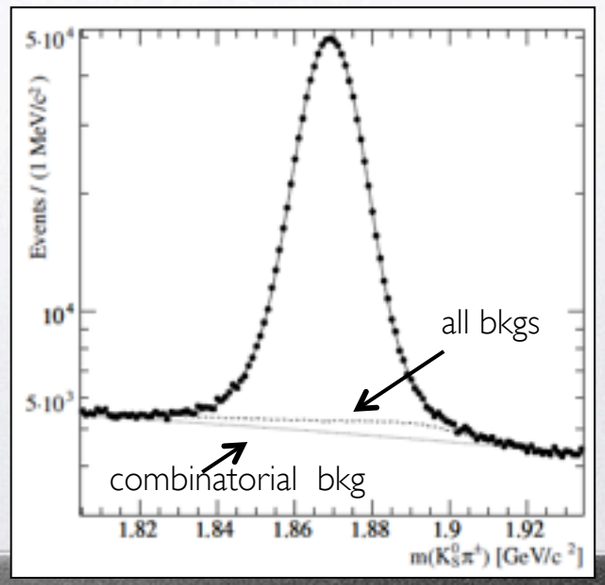
$$\mathcal{A}_{CP} = (-0.032 \pm 0.006)\%$$

Cabibbo Allowed (CA) diagram



Cabibbo Suppressed (CS) diagram

- Experimental challenges:
- Need high statistics and systematics under control
- Need to correct for detector induced asymmetry (use of control samples)
- No PID used
- Yield extraction from ML fit to $K_S\pi$ mass $N_{sig}=807\times10^3$

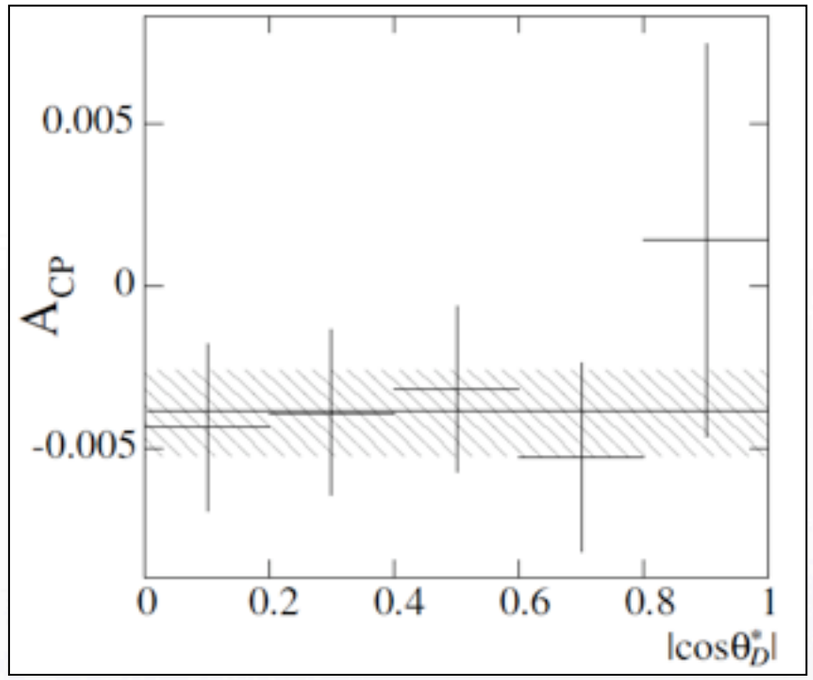


CPV in D: Results

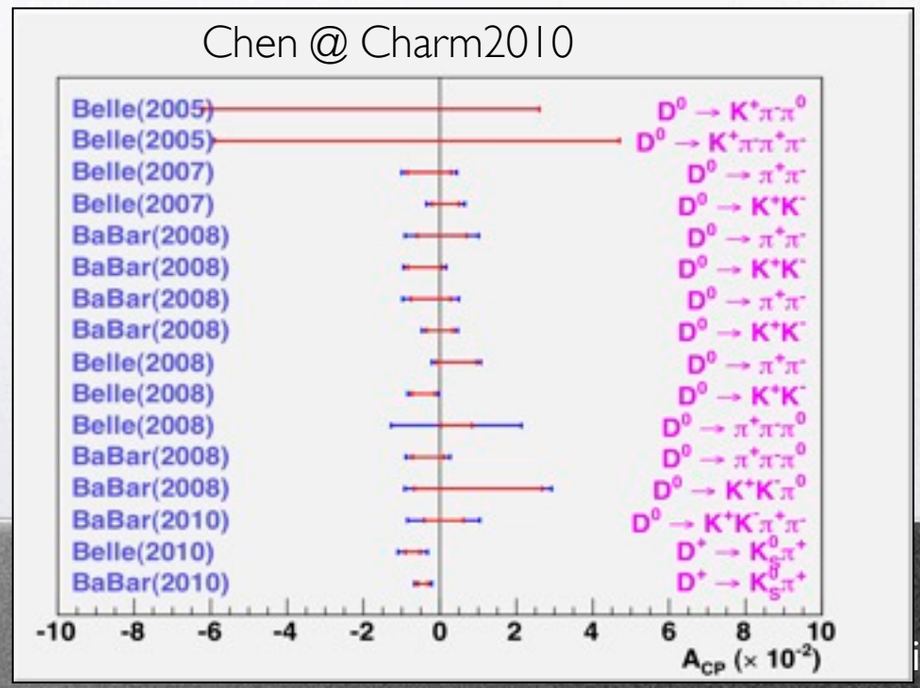
- Extract A_{CP} from asymmetry in yields:

$$\mathcal{A} = \frac{N_{D^+} - N_{D^-}}{N_{D^+} + N_{D^-}} = \mathcal{F}(\mathcal{A}_{CP}, \mathcal{A}_{FB}, \mathcal{A}_{det})$$

- FB asymmetry measured with A_{CP}
- Dominant systematics:
  - bias due to K/π contamination, detector induced asymmetry in π^+-π^- control sample accounting for 0.08%
  - K^0 regeneration: 0.06%



Results:
ACP = (0.44 ± 0.13_{stat}±0.10_{syst})
most precise measurement



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