Rare B Decays at BaBar

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Outline

Some recent BaBar results on rare B decay modes:

- Electroweak decays $B \rightarrow K^{(*)} l^+ l^-$
- Pure leptonic decays $B^+ \rightarrow l^+ \upsilon_l$
- Hadronic-penguin B decays

  Direct CP Asymmetry in B decays to $K^{\pm}\pi^{\mp}$

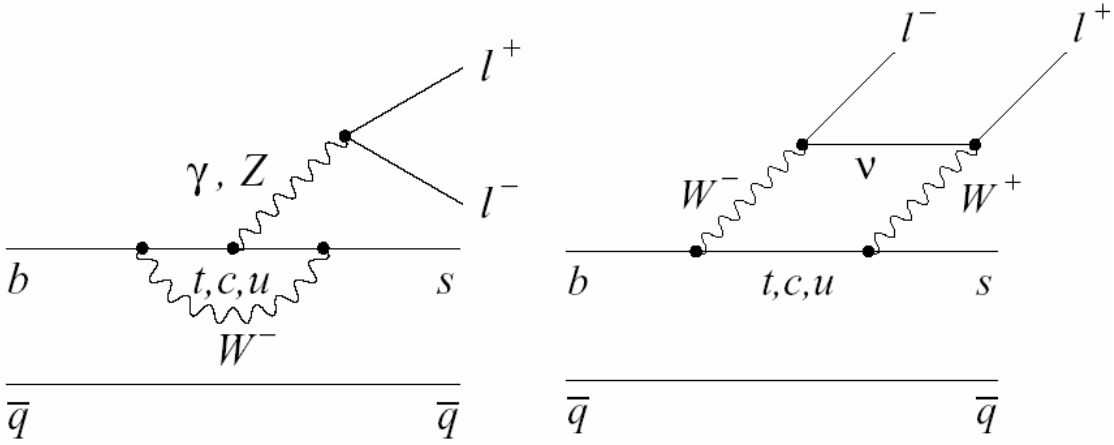
  Search for $B^+ \rightarrow K^0_s K^0_s \pi^+$

  Branching Fractions in $B^0 \rightarrow K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$
- Conclusions

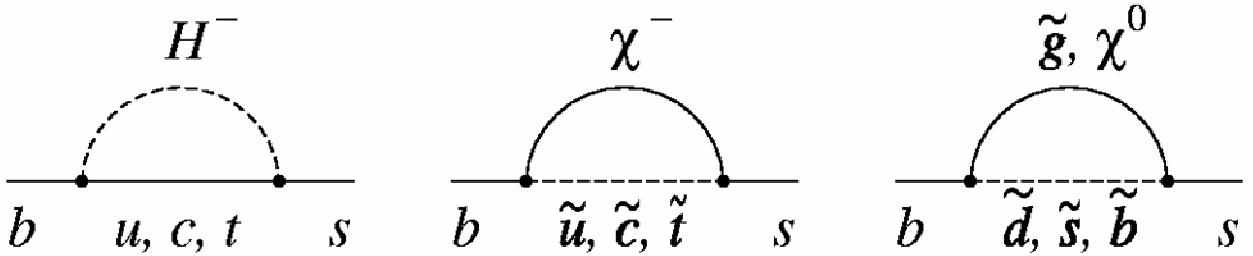
NB : All results are preliminary if published reference not given

$B \to K^{(*)} l^+ l^-$ Decays

- $B \to K^{(*)} e^+e^-$, $B \to K^{(*)} \mu^+\mu^-$: Forbidden at tree level in Standard Model (SM). Contributions from photon and Z penguins and from box diagram



- But contributions (same order as SM) from New Physics (NP) can appear in the loop (from charged Higgs boson, chargino, neutralino , gluino) affecting both rates and kinematic distributions



$B \to K^{(*)} l^+ l^-$ Decays

- In the rates sensitivity to NP in these exclusive modes limited by hadronic uncertainties : better to search for NP in rate asymmetries where part of the these uncertainties cancels

- Several observables useful to test the SM:

  - Direct CP asymmetry $$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+ \ell^-) - \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)} \ell^+ \ell^-) + \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}$$

  - Lepton-Flavor Ratio $$R_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)}$$

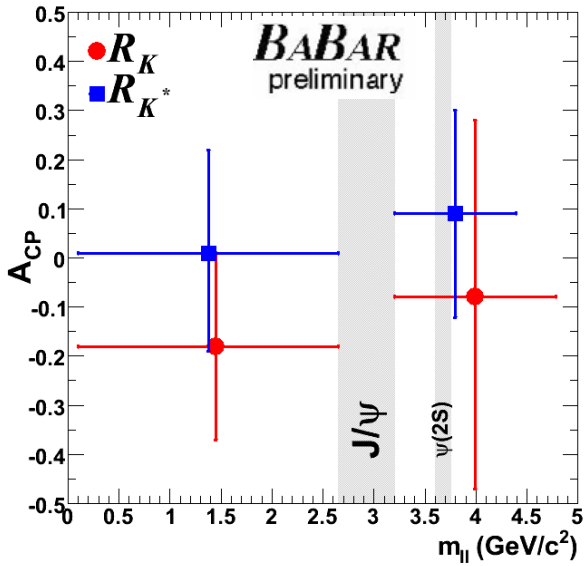
  - CP-averaged Isospin Asymmetry $$A_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0} \ell^+ \ell^-) - r\mathcal{B}(B^\pm \to K^{(*)\pm} \ell^+ \ell^-)}{\mathcal{B}(B^0 \to K^{(*)0} \ell^+ \ell^-) + r\mathcal{B}(B^\pm \to K^{(*)\pm} \ell^+ \ell^-)}$$
    $$r = \tau_0/\tau_+ = 1/(1.071 \pm 0.009)$$

For recent BaBar results on angular distributions in $B \to K^* l^+ l^-$ (forward-backward asymmetry and K* longitudinal polarization) : arXiv:0810.0837.v2

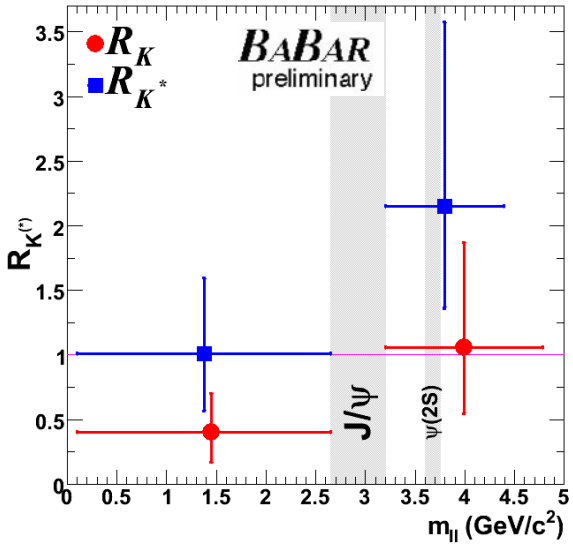
$B \to K^{(*)} l^+ l^-$ Decays

384 M $B\bar{B}$

- 10 Final States $B \to$ $\left\{ \begin{array}{l} K^+,\ K^0_S(\to \pi^+\pi^-) \\ K^{\pm}\pi^-,\ K^{\pm}\pi^0,\ K^0_S\pi^{\pm} \end{array} \right\}$ $\left\{ \begin{array}{l} e^+e^- \\ \mu^+\mu^- \end{array} \right\}$
- To exclude J/ψ resonance, analysis done in two distinct dilepton mass squared $q^2 = m_{ll}^2$ regions, low : 0.10-7.02 $(GeV/c^2)^2$ and high : > 10.24 $(GeV/c^2)^2$



Direct CP Asymmetry : expected O(10^{-4}) in SM but possible significant enhancement from NP (**arXiv:0805.2525**). Results consistent with SM



Lepton Flavor Ratio: In SM $R_{K(*)} \sim 1$; in 2HDM sensitive to charged Higgs at large tan β (**hep-ph/0004262**). Results consistent with SM.

Results in agreement with Belle (ICHEP'08)

$B \to K^{(*)} l^+ l^-$ Decays

CP-averaged Isospin Asymmetry $A^{K(*)}_I$

$|A_I^{K^{(*)}}|$ ~0.01 expected in SM

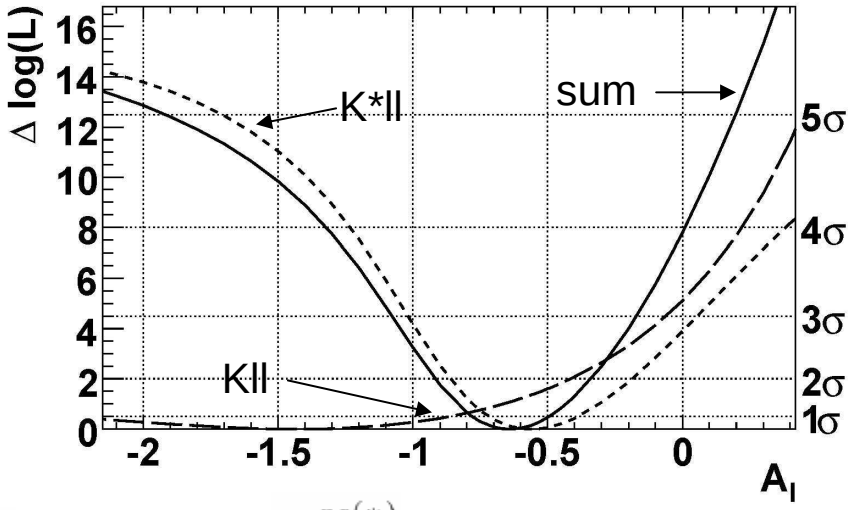
(**T. Feldmann-J. Matias, JHEP 0301,074(2003)**)

Measured in low, high and sum dilepton mass squared regions. No deviation from SM in high mass and in combined regions

Mode	combined q^2	low q^2	high q^2
$K\mu^+\mu^-$	$0.13^{+0.29}_{-0.37} \pm 0.04$	$-0.91^{+1.2}_{-\infty} \pm 0.18$	$0.39^{+0.35}_{-0.46} \pm 0.04$
Ke^+e^-	$-0.73^{+0.39}_{-0.50} \pm 0.04$	$-1.41^{+0.49}_{-0.69} \pm 0.04$	$0.21^{+0.32}_{-0.41} \pm 0.03$
$K\ell^+\ell^-$	$-0.37^{+0.27}_{-0.34} \pm 0.04$	$-1.43^{+0.56}_{-0.85} \pm 0.05$	$0.28^{+0.24}_{-0.30} \pm 0.03$
$K^*\mu^+\mu^-$	$-0.00^{+0.36}_{-0.26} \pm 0.05$	$-0.26^{+0.50}_{-0.34} \pm 0.05$	$-0.08^{+0.37}_{-0.27} \pm 0.05$
$K^*e^+e^-$	$-0.20^{+0.22}_{-0.20} \pm 0.03$	$-0.66^{+0.19}_{-0.17} \pm 0.02$	$0.32^{+0.75}_{-0.45} \pm 0.03$
$K^*\ell^+\ell^-$	$-0.12^{+0.18}_{-0.16} \pm 0.04$	$-0.56^{+0.17}_{-0.15} \pm 0.03$	$0.18^{+0.36}_{-0.28} \pm 0.04$
$K^*e^+e^-$	$-0.27^{+0.21}_{-0.18} \pm 0.03$	$-0.25^{+0.20}_{-0.18} \pm 0.03$	—

arXiv:0807.4119 submitted to PRL

Low q^2 Region



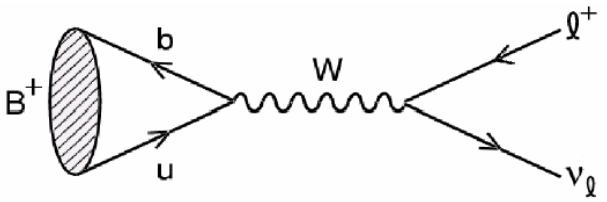
$A_I^{K^{(*)}}$ = -0.64+0.15 ± 0.03

Significance (syst included) to exclude $A^{K(*)}_I$ =0 :

Kll 3.2σ , K*ll 2.7σ, $K^{(*)}$ ll 3.9σ

consistent with Belle results ICHEP'08

Leptonic $B^+ \to l^+ \upsilon_l$ *Decays*



- In SM purely leptonic $B \to l^+ \upsilon_l$ ($l=\tau,\mu,e$) proceed through W boson annihilation (helicity suppressed) with a decay rate:

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

- In SM $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.59 \pm 0.40) \cdot 10^{-4}$
  $\mu\nu_\mu$ and $e\nu_e$ suppressed by 225 and 10^7

$$\begin{cases} V_{ub} = (4.39 \pm 0.33) \cdot 10^{-3} \text{ (HFAG)} \\ f_B = 216 \pm 22 \text{ [PRL95,212001(2005)]} \end{cases}$$

- Experimental access $f_B |V_{ub}|$ to test form factor QCD calculations
- In annihilation process possible contributions from NP. Charged Higgs boson effect may greatly change the BF:

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{SM} \times r_H$$

$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$

W-S Hou, PRD 48, 2342 (1993)

Leptonic $B^+ \to l^+ \upsilon_l$ Decays

459 M $B\bar{B}$

arXiv:0809.4027

- Signals $B^+ \to \tau^+\nu_\tau$, $\mu^+\nu_\mu$, $e^+\nu_e$ with $\tau^+ \to e^+\nu_e\nu_\tau$, $\mu^+\nu_\mu\nu_\tau$, $\pi^+\nu_\tau$, $\pi^+\pi^0\nu_\tau$
  searched in the recoil of semi-leptonic $B^- \to D^0 l^- \bar{\nu}_l X$ (tag B) (l=e, μ)

- Event candidate selection based on:
  - momentum of τ daughter
  - background suppression using event shape (LH ratios for $B\bar{B}$ and continuum)
  - hermeticity: extra energy **E_{extra}** not associated to tag B or signal B
- Number of expected background events estimated from E_{extra} sidebands
- Double tagged events and sidebands used as control samples

Results:

Mode	$N_{exp\ BKG}$	$N_{obs\ sig}$	Efficiency (ε)	Branching Fraction
$B^+ \to \tau^+\nu_\tau$	521 ± 31	610	$(10.54 \pm 0.41) \times 10^{-4}$	$(1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$
$B^+ \to \mu^+\nu_\mu$	15 ± 10	11	$(27.1 \pm 1.2) \times 10^{-4}$	$< 11 \times 10^{-6}$ @ 90% CL
$B^+ \to e^+\nu_e$	24 ± 11	17	$(36.9 \pm 1.5) \times 10^{-4}$	$< 7.7 \times 10^{-6}$ @ 90% CL

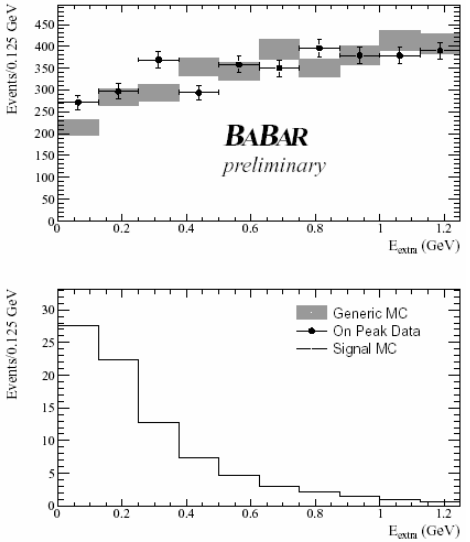
In $\tau^+\nu_\tau$ B decay BF significance of 2.4 σ (syst. Incl.) UL = $3.2\ 10^{-4}$ at 90% CL

Leptonic $B^+ \to l^+ \upsilon_l$ *Decays*

- Previous BaBar result with hadronic tag:

383M BB, PRD77, 011107 (2008)

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2) \times 10^{-4}$$



- Combining the two results :

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.8 \pm 0.6) \times 10^{-4}$$

3.2 σ (syst. incl.)

- Belle results:

449M BB, PRL99, 251802 (2006)

– Hadronic	$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$	3.5σ
– SL	$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$	3.8σ

657 M $B\bar{B}$
axXiv:0809.3834

- $B^+ \to \mu^+ \upsilon_\mu$ decay has been searched also with inclusive tagging with 447 M $B\bar{B}$
  No signal event found and set an UL of $\mathbf{1.3 \cdot 10^{-6}}$ at 90% CL

arXiv:0807.4187

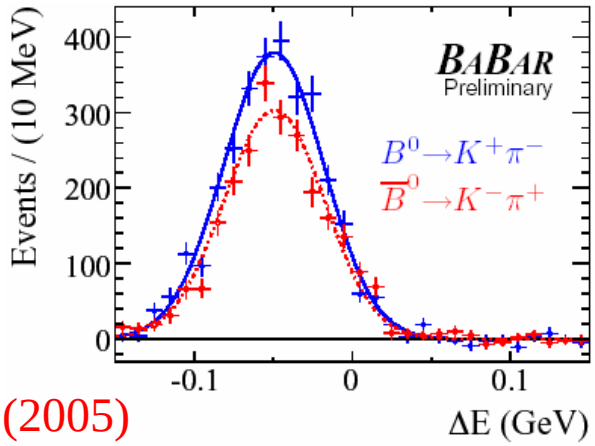
Direct CP Asymmetry in

$$\mathcal{A}_{K^\pm\pi^\mp} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)}$$

467 M $B\overline{B}$

arXiv:0807.4226

- We measure $A_{K^+\pi^-} = -0.107 \pm 0.016^{+0.006}_{-0.004}$ with 6.1σ significance.



- $\mathcal{A}_{K^\pm\pi^0} = 0.030 \pm 0.039 \pm 0.010$

  383 M $B\overline{B}$ BaBar PRD76,091102(2007)

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.137 \pm 0.044$$

expected zero : Gronau and Rosner PL B627,82(2005)

- Same effect seen also in Belle (**Nature 452, 332(2008)**)

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

- HFAG average: $\Delta\mathcal{A} = 0.147 \pm 0.028$ (5.3σ)

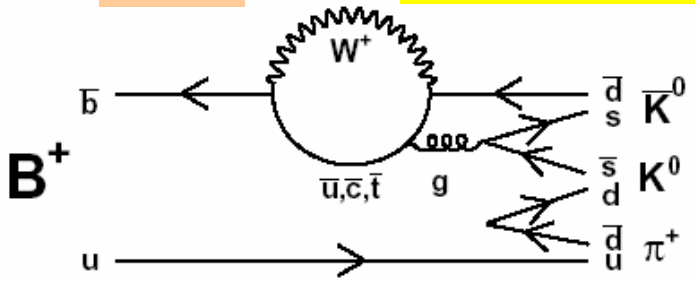
➢ Large color suppressed amplitude ? M. Gronau-J. L. Rosner, **PL B644,237(2007)**

➢ Possible new-physics effect ? W.S. Hou et al., **Eur. Phys. J. C. 51, 55(2007)**

Search for $B^+ \to K^0_s K^0_s \pi^+$

New

465 M $B\bar{B}$



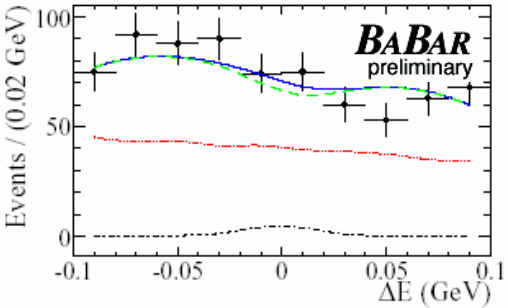
- Suppressed decay in SM : it proceeds through hadronic $\bar{b} \to \bar{d}$ penguin transition. Non resonant and Q2B intermediate modes can contribute with BFs of order $\sim 10^{-6}$ (**PRD60,054029(1999), PRD75,014019(2007)**)

  Existing UL at 90% CL: **$3.2 \cdot 10^{-6}$** (Belle, **PRD69, 012001(2004)**)

- In $B^+ \to K^+K^-\pi^+$ BaBar found a peak ($f_x(1500)$ at 1.5 GeV/c^2 in K^+K^- inv-mass (**PRL99,221801(2007)**). Observation of $f_x(1500) \to K^0_S K^0_S$ in the target decay mode would provide information on the spin or quark content of $f_x(1500)$.

- Inclusive analysis incorporating both resonant and nonresonant modes . No significant signal, BF= **$(2.5 \pm 2.4 \pm 0.9) \cdot 10^{-7}$** UL **$5.1 \cdot 10^{-7}$** 90% CL

- No evidence for $f_x(1500) \to K^0_S K^0_S$. Models with even spin and decays with isospin symmetry are disfavored.



Projection onto ΔE and fit results. Black curve signal

$B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$

- CKM $\alpha_{e\,ff}$ measured by BaBar from TD CP-asymmetries in the decays $B^0(\bar{B}^0) \to a_1(1260)^{\pm}\pi^{\mp}$ (**PRL 98, 181803(2007)**) — 454 M $B\bar{B}$

- Set bound $|\alpha - \alpha_{eff}|$ using SU(3) symmetry using the related decays with $\Delta S=1$: $B \to a_1(1260)\,K$ and $B \to K_{1A}\,\pi$ (K_{1A} mixture of $K_1(1270)$ and $K_1(1400)$ M. Gronau and J. Zupan, **PRD 73,057502 (2006)**

- Improved analysis modelling interference effects in the intermediated states using K-matrix formalism (C. Daum et al., **Nucl. Phys. B187, 1(1981)**)
  2 real production parameters (θ,φ): relative amplitude and phase between $K_1(1270)$ and $K_1(1400)$.

axXiv:0807.4760

- Likelihood scan w.r.t. θ,φ . We measure (significanza (syst. incl.) **> 5.1 σ**)

$$\mathcal{B}(B^0 \to K_1(1270)^+\pi^- + K_1(1400)^+\pi^-) = (31.0 \pm 2.7 \pm 6.9) \times 10^{-6}$$

Conclusions

- We have presented some of the recent BaBar updated measurements in:
  electroweak (rate asymmetries in $B \to K^{(*)} l^+ l^-$), **pure leptonic** (BF in $B^+ \to l^+ \upsilon_l$) , and **charmless B decays** (Direct CP asymmetry in $B \to K\pi$ and BF in $B^0 \to K_1(1270)^+ \pi^-$ and $K_1(1400)^+ \pi^-$)

- Search for $\mathbf{B^+ \to K^0_S K^0_S \pi^+}$ (UL $5.1 \cdot 10^{-7}$ at 90% CL). No evidence of a structure $f_x(1500)$ in $K^0_S K^0_S$ inv. mass at 1.5 GeV/c^2

- Results **consistent** in general with SM expectations. There is disagreement with SM (hints to new physics?) in : Isospin asymmetry in $B \to K^{(*)} l^+ l^-$ decays
  Differernt direct CP asymmetry in B to $K^\pm \pi^0$ and $K^\pm \pi^\mp$

- It is evident that we need much more precise measurements to improve our sensitivity to SM deviations and to NP effects:

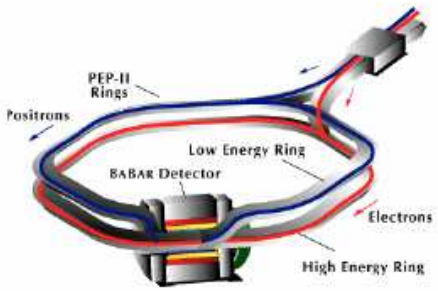
LHCb for some measurements

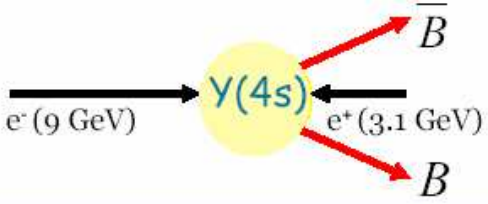
Super Flavor factories for other measurements

Backup Slides

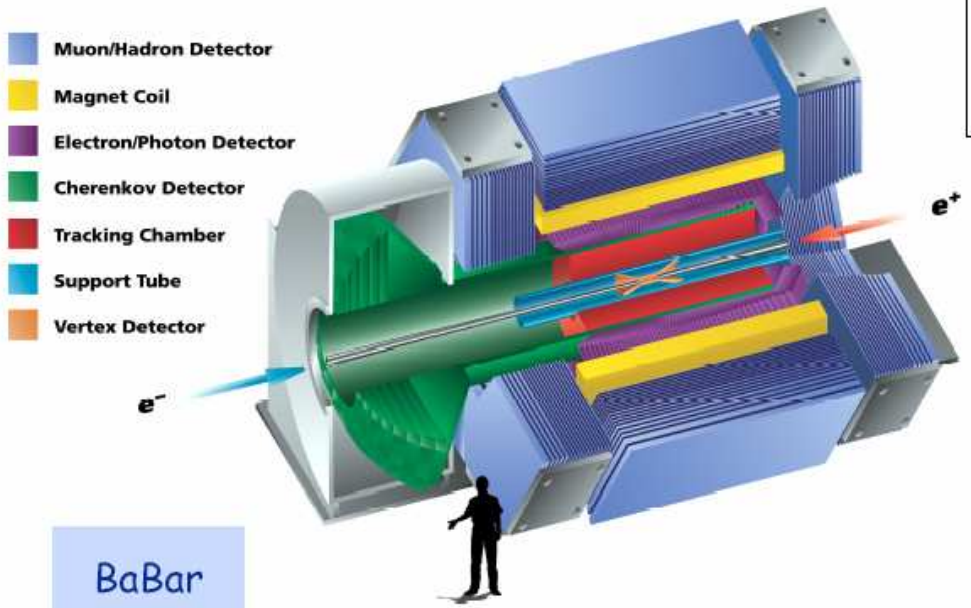
Detector and Dataset

PEP II



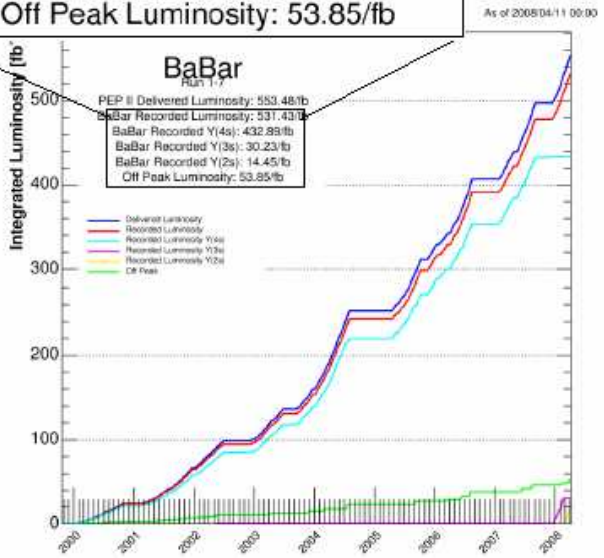


B Factory Asimmetrica



BaBar

BaBar Recorded Luminosity: 531.43/fb
BaBar Recorded Y(4s): 432.89/fb
BaBar Recorded Y(3s): 30.23/fb
BaBar Recorded Y(2s): 14.45/fb
Off Peak Luminosity: 53.85/fb



$B^+ \to \mu^+ \upsilon_\mu$ Decays (inclusive)

447 M $B\bar{B}$

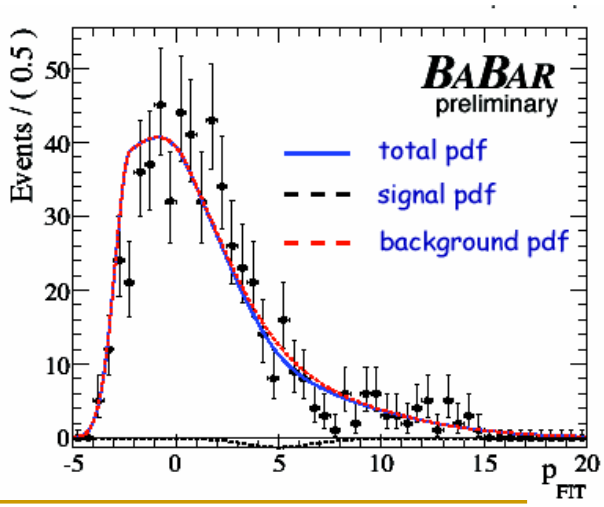
- Selection: muon with highest momentun: two-body B decay:
  muon $p_{Rest} \approx 2.46$ GeV/c in B rest frame

arXiv:0807.4187

- From all other particles in the event we reconstruct the Btag

- Signal and background extracted from a Fisher discriminant based on p_{Rest} and p_{CM} : $p_{FIT} = a_1 + a_2 \cdot p_{CM} + a_3 \cdot p_{Rest}$

source	value ± tot err
N_{bb}	$4.47\ 10^8$ ± 1.1%
Sig eff.	0.0464 ± 0.0019
Sig yield	-11.9 ± 20.3



BF < 1.3×10^{-6} at 90% CL

$1.7 \cdot 10^{-6}$ at 90% CL (Belle)

$B \to K^{*\pm(0)} \nu\,\nu$ Decays

454 M $B\bar{B}$

- EW B decays in SM proceed via box diagram and electroweak penguin but NP effects (as from nonstandard Z couplings [G. Buchalla et al., PRD63, 014015(2000)], unparticles [T.M.Aliev et al., **arXiv:0705.4542**], dark matter particles [C. Bird et al., PRL93,201803(2004)] may be important and observable.
- Recoil hadronic and semileptonic tags ; E_{extra} main discriminating variable. Fit to E_{extra} in SL tag analysis and to a Neural Network in the had tag.

$$B \to Dl\nu X \quad \left[X = \gamma, \pi \text{ or nothing}\right]$$

$$B \to DX \quad \left[X = n\pi + mK + rK_S^0 + q\pi^0 \quad n+m+r+q<6\right]$$

$$K^{*+} \to K_S^0(\pi^+\pi^-)\pi^+$$
$$K^{*+} \to K_S^0(\pi^0\pi^0)\pi^+(\mathrm{SL})$$
$$K^{*+} \to K^+\pi^0$$
$$K^{*0} \to K^+\pi^-$$

- No significant signals, Bayesian UL :
  - Model independent analysis
  - Consistent with SM

$$\mathcal{B}(B^+ \to K^{*+}\nu\bar{\nu}) < 8 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) < 12 \times 10^{-5}$$
$$\mathcal{B}(B \to K^{*}\nu\bar{\nu}) < 8 \times 10^{-5}.$$

arXiv:0808.1338

Polarization in B→ φK(*) Decay

465 M $B\bar{B}$

- Rare decay described by a gluonic b→s penguin diagram. Three helicity amplitudes (A_0, A_-, A_+). In SM helicity amplitudes in B→VV follow the hierarchy pattern: $|A_0| \sim 1 >> |A_+| \sim m_V/m_B >> |A-| \sim (m_V/m_B)^2$
  Fraction of longitudinal polarization $f_L = |A_0|^2/(|A_0|^2 + |A_+|^2 + |A_-|^2)$
  $f_L = 1 - O[(m_V/m_B)^2]$ **A. L. Kagan PL B601, 151(2004)**
- In B →φ $K^{(*)}_J$ (J= 1,2) longitudinal polarization (and several other physical quantities including BF and CP-violating parameters) measured in a full angular analysis: **f_L (J=1) = 0.494 ± 0.034 ± 0.013** , f_L (J=2) = $0.901^{+0.046}_{-0.058} \pm 0.037$

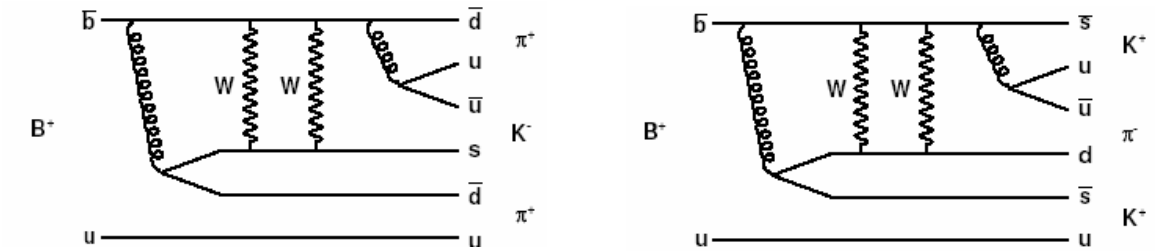
arXiv:0808.3586

- Unexpected low f_L (confirmed by Belle) . Same anomaly also found in other VV decays described by penguin b→s (ρ^0 K^{*0} (BaBar), ω K^{*0} (Belle) . Such an anomaly not found in b→u tree transition (B→$\rho^0\rho^0$, $\rho^+\rho^-$, $\rho^+\rho^0$) **HFAG –Sept 2008**

$B^+ \to K^-\pi^+\pi^+$ and $K^+K^+\pi^-$

465 M $B\bar{B}$

- Wrong sign transitions $b \to \bar{d}\bar{d}s$ and $b \to \bar{s}\bar{s}d$ SM-suppressed , with BFs of $O(10^{-14})$ and $O(10^{-11})$, respectively **T. E. Browder et al., arXiv:0802.3201[hep-ph]**



- MSSM enhancements up to $O(10^{-9})$ and $O(10^{-6})$ **S. Fajfer et al. PRD74, 034027 (2006)**

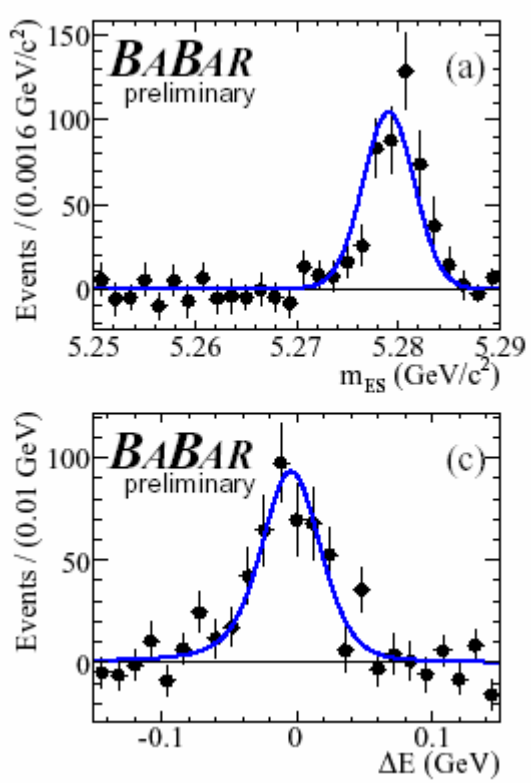
- No significant signals observed

$B(B^+ \to K^-\pi^+\pi^+) = (1.8 \pm 4.3 \pm 0.9) \cdot 10^{-7}$ (<9.5 10^{-7} at 90% CL)

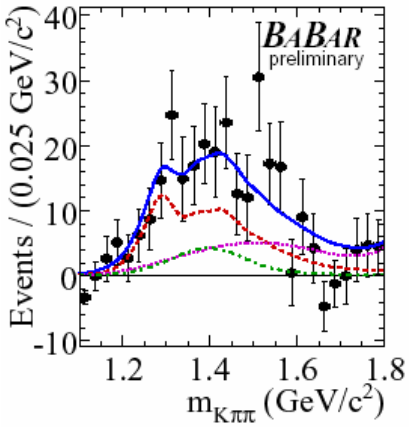
$B(B^+ \to K^+K^+\pi^-) = (-3.2 \pm 2.3^{+1.0}_{-0.6}) \cdot 10^{-7}$ (<1.6 10^{-7} at 90% CL)

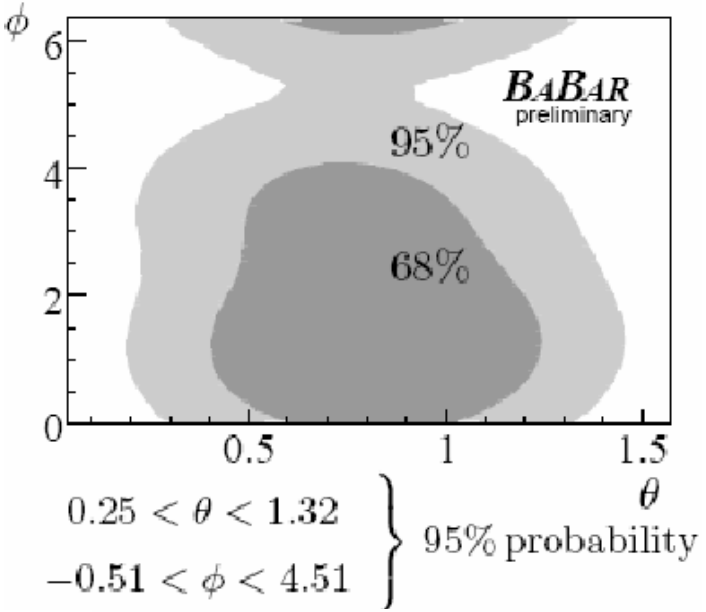
arXiv:0808.0900 → PRD-RC

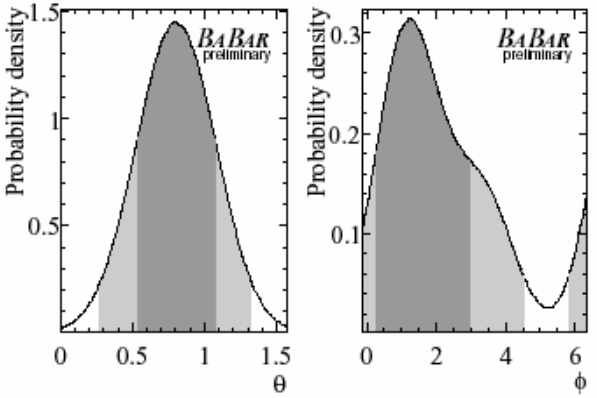
$B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$



axXiv:0807.4760







See **PRL 100,051803** for the observations of :

$B^0 \to a_1(1260)^- K^+$ (5.1 σ syst incl) and

$B^+ \to a_1(1260)^+ K^0$ (6.2 σ syst incl)