



Latest results on radiative penguin B decays and Searches for Lepton-Number Violation in $B^+ \rightarrow X^- l^+ l'^+$



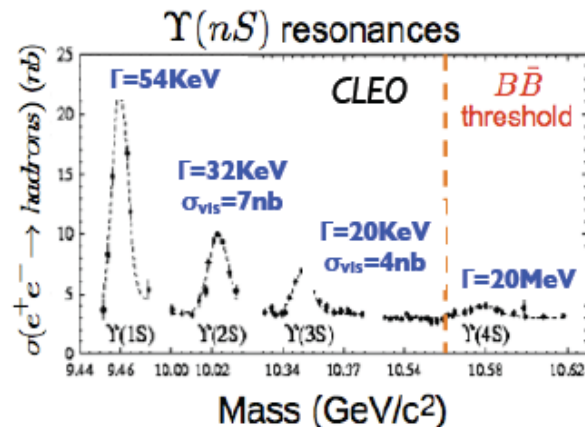
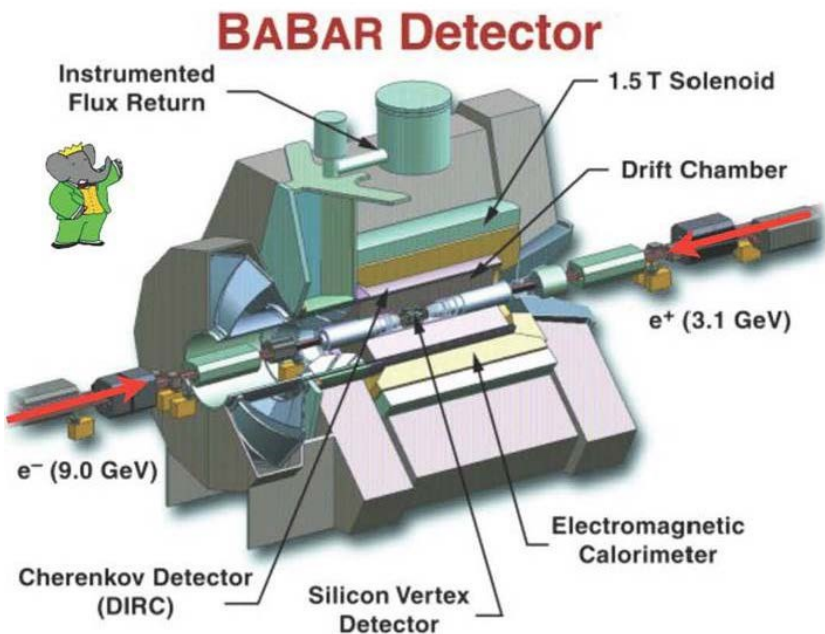
On behalf of the BaBar Collaboration, EPS 2013, 18th – 24th July 2013, Stockholm

- Radiative Penguin B decays
 - Direct Asymmetries in $B \rightarrow X_s \gamma$ [to be submitted to PRD]
 - Search for $B \rightarrow \pi/\eta l^+ l^-$ [arXiv:1303.6010]
- Lepton-Number Violation (LNV)
 - $B^+ \rightarrow X^- l^+ l'^+$ [to be submitted to PRD-RC]

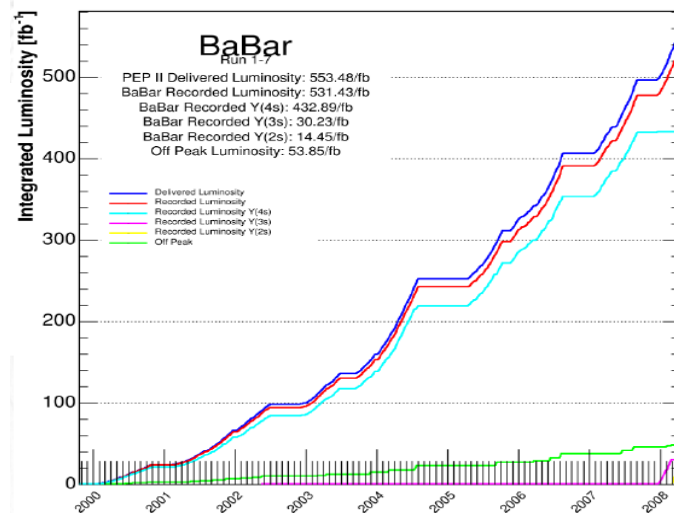
BaBar and PEP-II : $e^+e^- \rightarrow \Upsilon(nS)$



Asymmetric beam momenta, $\Upsilon(nS)$ production, low multiplicity, low background, π/K particle identification, good muon and electron identification with wide coverage.



$L(4S) = 424 \text{ fb}^{-1}$	$N(4S) = 471 \text{ M}$
$L(3S) = 28 \text{ fb}^{-1}$	$N(3S) = 121 \text{ M}$
$L(2S) = 14 \text{ fb}^{-1}$	$N(2S) = 99 \text{ M}$
	$N(\tau\tau) \sim 450 \text{ M}$



Similar number of B-mesons, charm-mesons and τ pairs produced: ~ 450 million

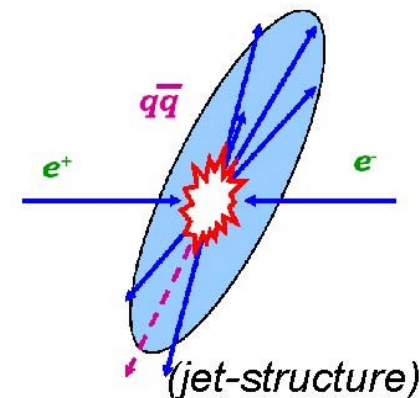
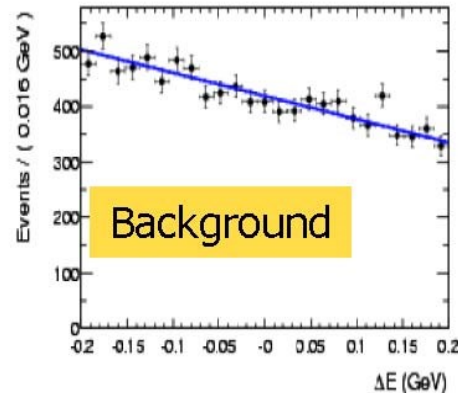
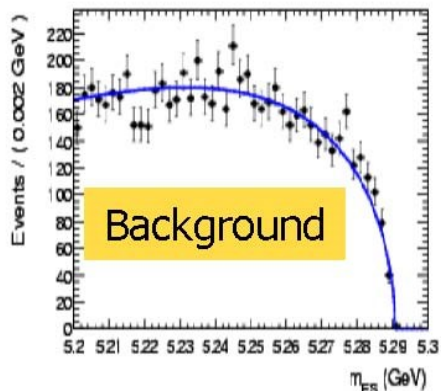
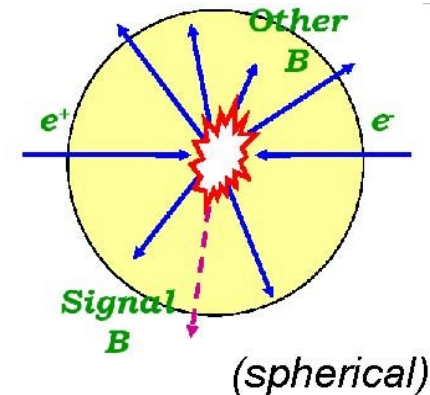
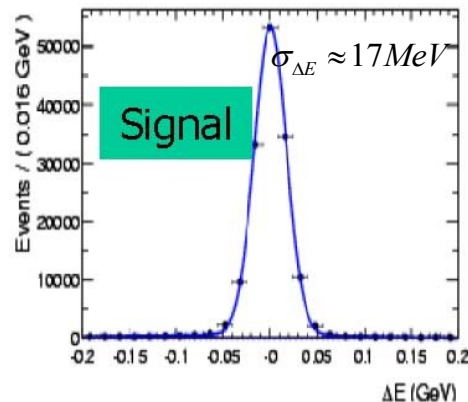
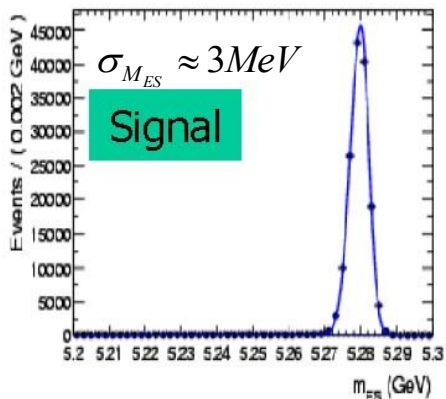
Typical Analysis Techniques



$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

$$\Delta E = E_B^* - E_{beam}^*$$

Event Topology

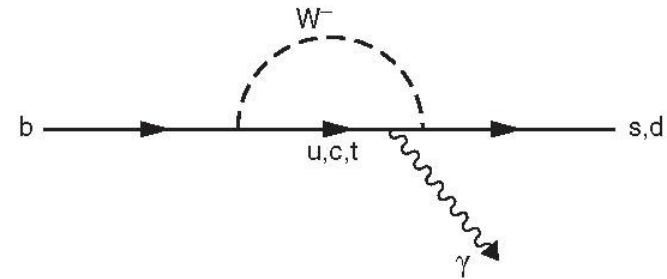


Plus: blinded analysis, multivariate discriminants, Maximum Likelihood (ML) fits

Introduction to $B \rightarrow X_s \gamma$



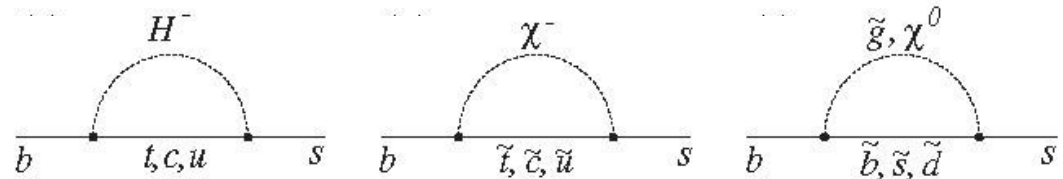
- $B \rightarrow X_s \gamma$ and $B \rightarrow X_s l^+ l^-$ are flavor-changing neutral current (FCNC) processes, forbidden in SM at tree level.



- SM NNLO prediction: $\mathcal{B}(B \rightarrow X_s \gamma) = (3.14 \pm 0.22) \times 10^{-4} (E_\gamma > 1.6 \text{ GeV})$
- Effective Hamiltonian can be factorized in terms of short-distance (C_i) and long-distance (O_i , Wilson Coefficients) terms:

$$H_{eff} = \frac{4G_F}{\sqrt{2}} \sum_i C_i(\mu) O_i$$

- New physics can enter into loops.
 - Can modify or introduce new Wilson coefficients
 - Signature is modified branching fractions, angular distributions, lepton flavor ratios, CP Asymmetries.





- The CP asymmetry A_{CP} is defined as:

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow \bar{X}_s \gamma) - \Gamma(B \rightarrow X_s \gamma)}{\Gamma(\bar{B} \rightarrow \bar{X}_s \gamma) + \Gamma(B \rightarrow X_s \gamma)}$$

- The SM prediction is $-0.6\% < A_{CP} < 2.8\%$
- Present world average (WA) is $A_{CP} = (-0.8 \pm 2.9)\%$
- Difference for charged and neutral B decays:

$$\Delta A_{CP} = A_{CP}(B^+ \rightarrow X_s^+ \gamma) - A_{CP}(B^0 \rightarrow X_s^0 \gamma)$$

- ΔA_{cp} depends on C_7^{eff} and C_8^{eff}

$$\Delta A_{CP}(X_s \gamma) = 4\pi^2 \alpha_s \frac{\bar{\Lambda}_{78}}{m_b} \Im\left(\frac{C_8^{\text{eff}}}{C_7^{\text{eff}}}\right) \approx 0.12 \frac{\bar{\Lambda}_{78}}{100 \text{ MeV}} \Im\left(\frac{C_8^{\text{eff}}}{C_7^{\text{eff}}}\right) \quad 17 \text{ MeV} < \bar{\Lambda}_{78} < 190 \text{ MeV}$$

Benzke et al PRL 106, 141801 (2011)

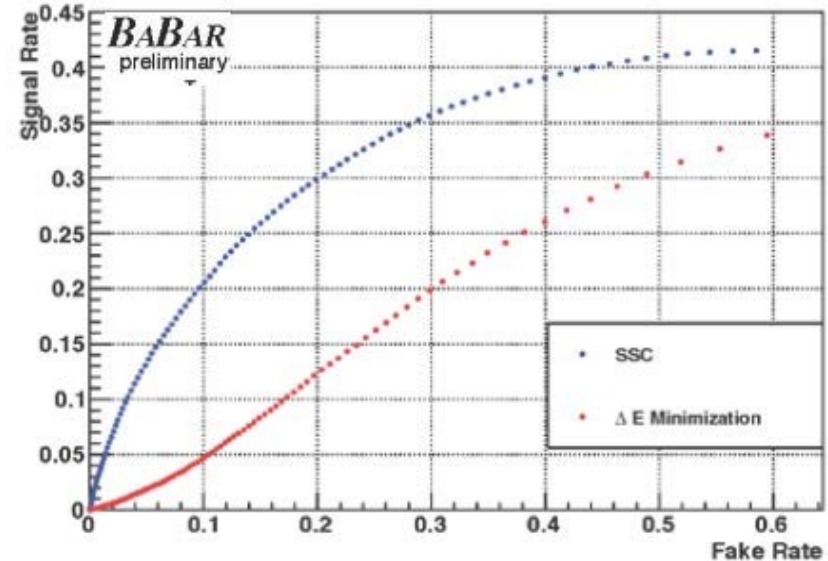
- In SM, C_7^{eff} and C_8^{eff} are real $\Rightarrow \Delta A_{cp} = 0$

$B \rightarrow X_s \gamma$: Event Selection for A_{CP}



- Full BaBar sample $(471 \pm 1) \times 10^6$ $B\bar{B}$ pairs.
- Reconstruct **16** exclusive modes to measure A_{CP} ; further **22** modes reconstructed to eliminate peaking background
- Two multivariate classifiers used.
 - **Signal Selecting Classifier (SSC)**: based on signal properties. Factor 2 improvement compared to using ΔE alone.
 - **Background Rejection Classifier (BRC)**: Based on event shapes.
 - Trained in four X_s mass regions, selection criteria based on optimizing $S/\sqrt{S+B}$.

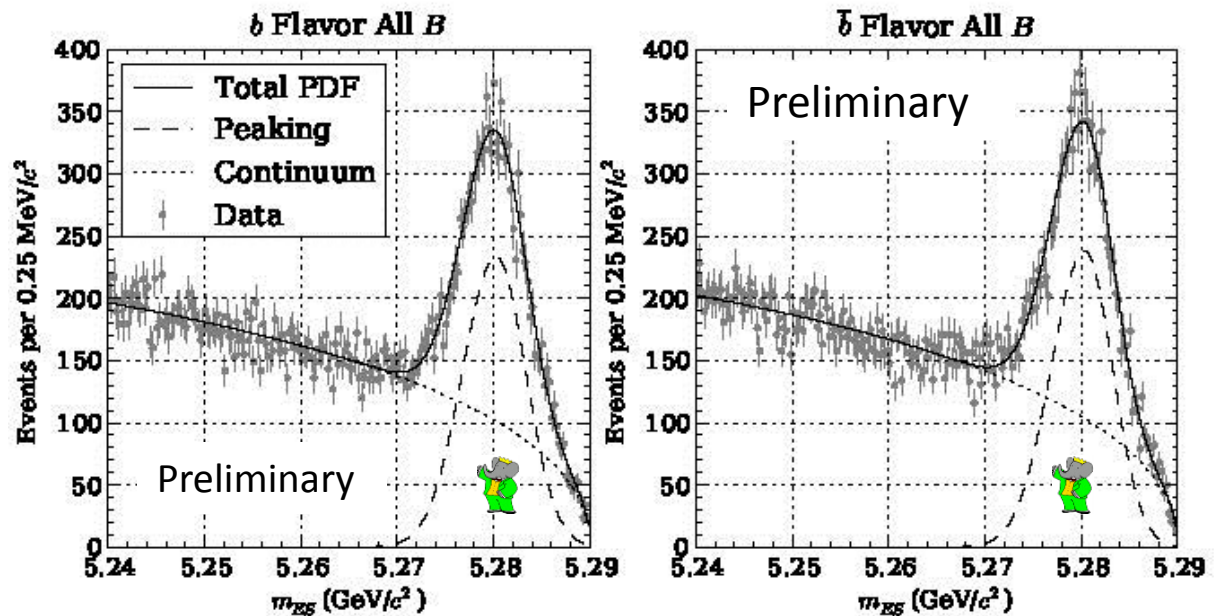
Decay Mode	Decay Mode
1 $B^+ \rightarrow K_S^0 \pi^+ \gamma$	9 $B^+ \rightarrow K^+ \pi^+ \pi^- \pi^0 \gamma$
2 $B^+ \rightarrow K^+ \pi^0 \gamma$	10 $B^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0 \gamma$
3 $B^0 \rightarrow K^+ \pi^- \gamma$	11 $B^0 \rightarrow K^+ \pi^+ \pi^- \pi^- \gamma$
4 $B^+ \rightarrow K^+ \pi^+ \pi^- \gamma$	12 $B^0 \rightarrow K^+ \pi^- \pi^0 \pi^0 \gamma$
5 $B^+ \rightarrow K_S^0 \pi^+ \pi^0 \gamma$	13 $B^+ \rightarrow K^+ \eta \gamma$
6 $B^+ \rightarrow K^+ \pi^0 \pi^0 \gamma$	14 $B^0 \rightarrow K^+ \eta \pi^- \gamma$
7 $B^0 \rightarrow K^+ \pi^- \pi^0 \gamma$	15 $B^+ \rightarrow K^+ K^- K^+ \gamma$
8 $B^+ \rightarrow K_S^0 \pi^+ \pi^- \pi^+ \gamma$	16 $B^0 \rightarrow K^+ K^- K^+ \pi^- \gamma$



$B \rightarrow X_s \gamma$: Direct A_{CP} results



- $1.6 < E^*_\gamma < 3.0$ GeV, $0.6 < m_{X_s} < 3.2$ GeV/ c^2
- B^+ tagged by overall charge, B^0 by Kaon charge.
- Fit m_{ES} for B and \bar{B} tagged samples simultaneously to extract A_{CP}

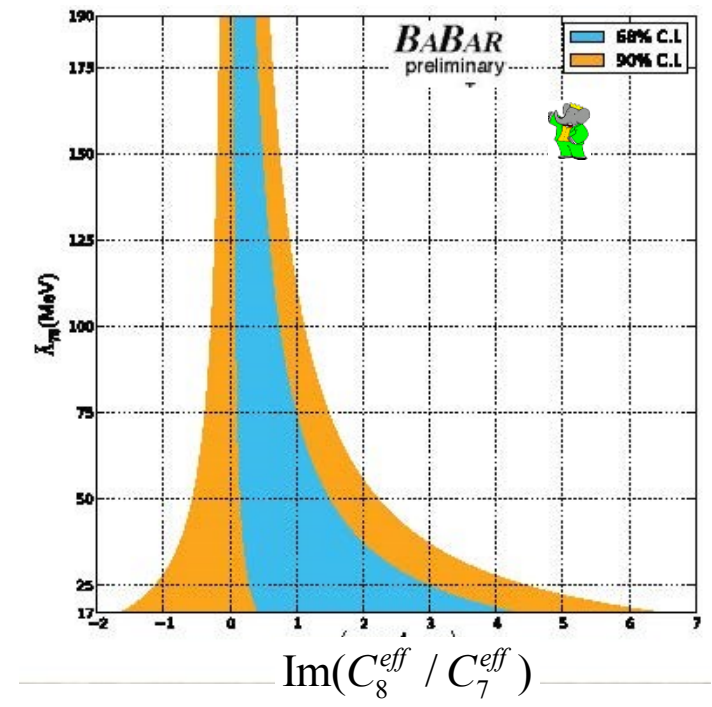
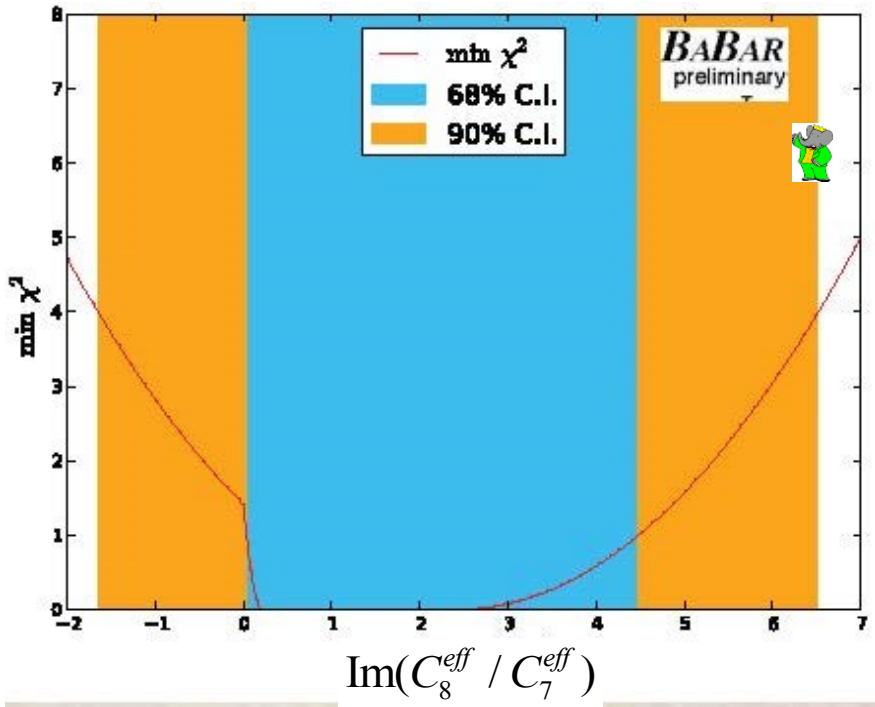


- After corrections for backgrounds and detector K^+/K^- response: $A_{CP} = (1.7 \pm 1.9 \pm 1.0)\%$
- Agrees with SM : $-0.6\% < A_{CP} < 2.8\%$

$B \rightarrow X_s \gamma : \Delta A_{CP}$ and Wilson Coefficients

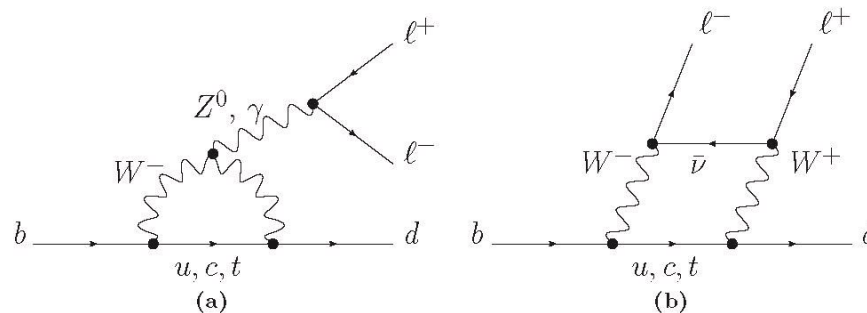


- From simultaneous fit to charged and neutral B samples:
 - $\Delta A_{CP} = (5.0 \pm 3.9 \pm 1.5)\%$
- Set 90% CL constraints on $Im(C_8^{eff}/C_7^{eff})$:
 - $-1.64 < Im(C_8^{eff}/C_7^{eff}) < 6.52$.



- First $\Delta A_{CP}(X_s \gamma)$ measurement and first constraint on C_8^{eff}/C_7^{eff} ratio.

- SM mediated by γ or Z-penguin and WW box diagrams:



- Suppressed compared to $b \rightarrow s l^+ l^-$: $|V_{td}/V_{ts}|^2 \sim 0.04$
- SM predictions :

$$\mathbf{B}(B^+ \rightarrow \pi^+ l^+ l^-) = (1.4 - 3.3) \times 10^{-8}$$

$$\mathbf{B}(B^+ \rightarrow \eta^+ l^+ l^-) = (2.5 - 3.7) \times 10^{-8}$$

- New Physics can alter decay rates, flavor couplings, isospin, A_{CP} and A_{FB} asymmetries.

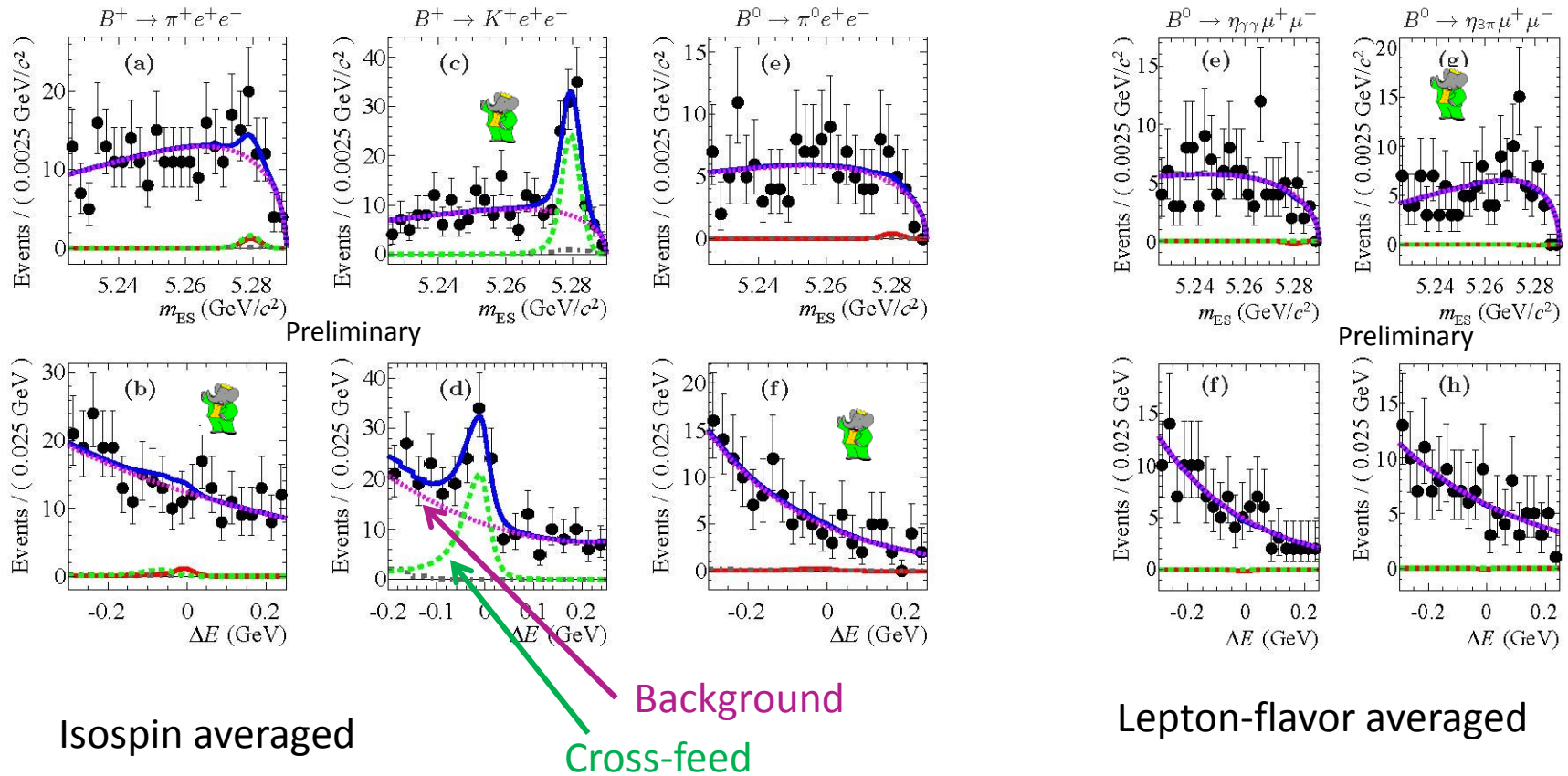


- Fully reconstruct 8 $B \rightarrow \pi/\eta l^+ l^-$ in $471 \times 10^6 B\bar{B}$ pairs.
 - $\pi^+, \pi^0, \eta \rightarrow \gamma\gamma, \eta \rightarrow \pi^+ \pi^- \pi^0$, recoiling against $e^+ e^-$ or $\mu^+ \mu^-$
 - Veto J/ψ and $\psi(2S)$ (but used to validate fit)
 - $P_l > 300$ MeV/c and $E_\gamma > 50$ MeV
 - Suppress $B\bar{B}$ and $q\bar{q}$ continuum backgrounds with multivariate discriminants (like BaBar $B \rightarrow K^{(*)} l^+ l^-$ angular analyses).
- Simultaneously fit to M_{ES} and ΔE .

$B \rightarrow \pi/\eta \ell^+ \ell^-$: Preliminary Results



- Produce preliminary results for isospin-averaged, lepton-flavor averaged:



B → π/η l⁺l⁻ : Preliminary Results



- No signal seen.
 - First results for B → η l⁺l⁻
 - Best limits for B⁰ → π⁰ l⁺l⁻
- $B(B^+ \rightarrow \pi^0 l^+ l^-) < 5.3 \times 10^{-8}$ (90% CL)
- Not precise enough to match LHCb B⁺ → π⁺ μ⁺ μ⁻
 - Limits are within a factor 2-3 of SM predictions.



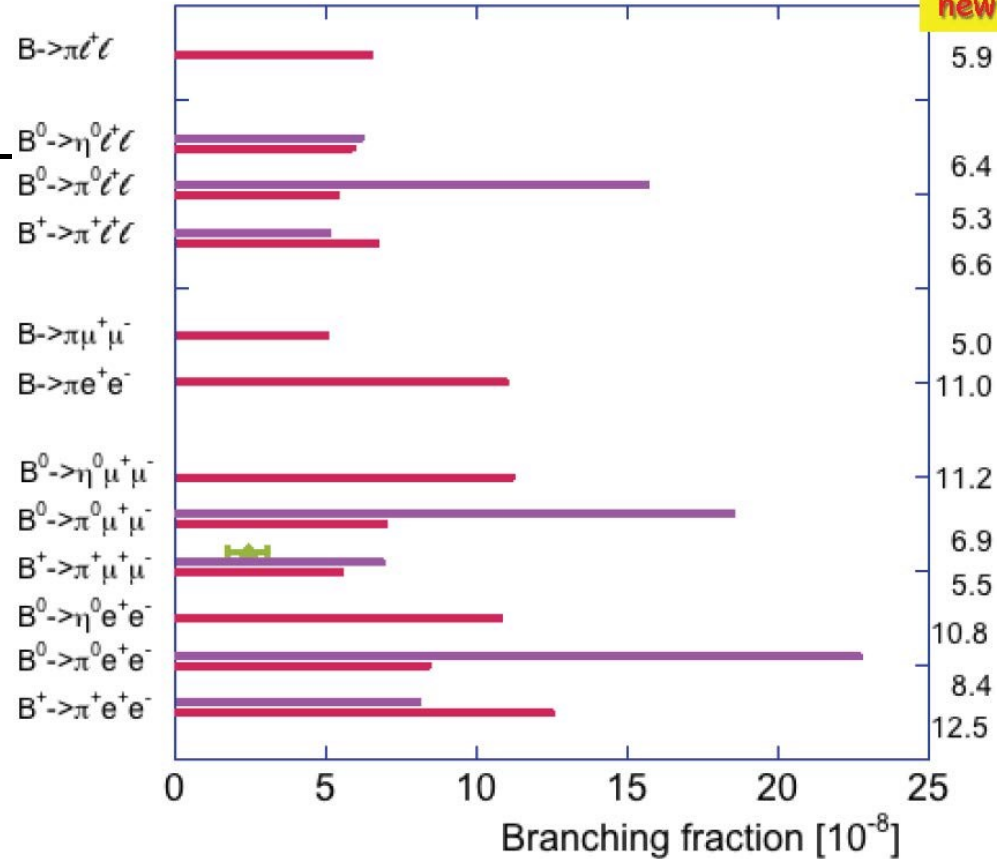
90% CL upper limit



BABAR
Belle
LHCb



new

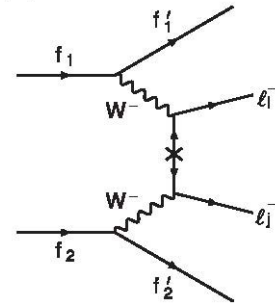


$B^+ \rightarrow X^- l^+ l'^+$: Introduction



- Lepton Number Violation (LNV) in SM only possible at very high energies/densities.
- Many, if not most, New Physics scenarios introduce LNV. Example scenario :

– Majorana neutrino exchange.



- Many modes not searched for since CLEO
- Search for 11 modes:

– $B^+ \rightarrow \rho^- (\rightarrow \pi^- \pi^0) l^+ l'^+$

– $B^+ \rightarrow K^{*-} (\rightarrow K_S^0 \pi^- \text{ and } \rightarrow K^- \pi^0) l^+ l'^+$

– $B^+ \rightarrow D^- (\rightarrow K^- \pi^- \pi^+) l^+ l'^+$

– $B^+ \rightarrow K^- / \pi^- e^+ \mu^+$

Previous/related results :

CLEO: PRD 65, 111102 (2002)

Belle: PRD 84, 071106 (2011)

BaBar: PRD 85, 071102 (2012)

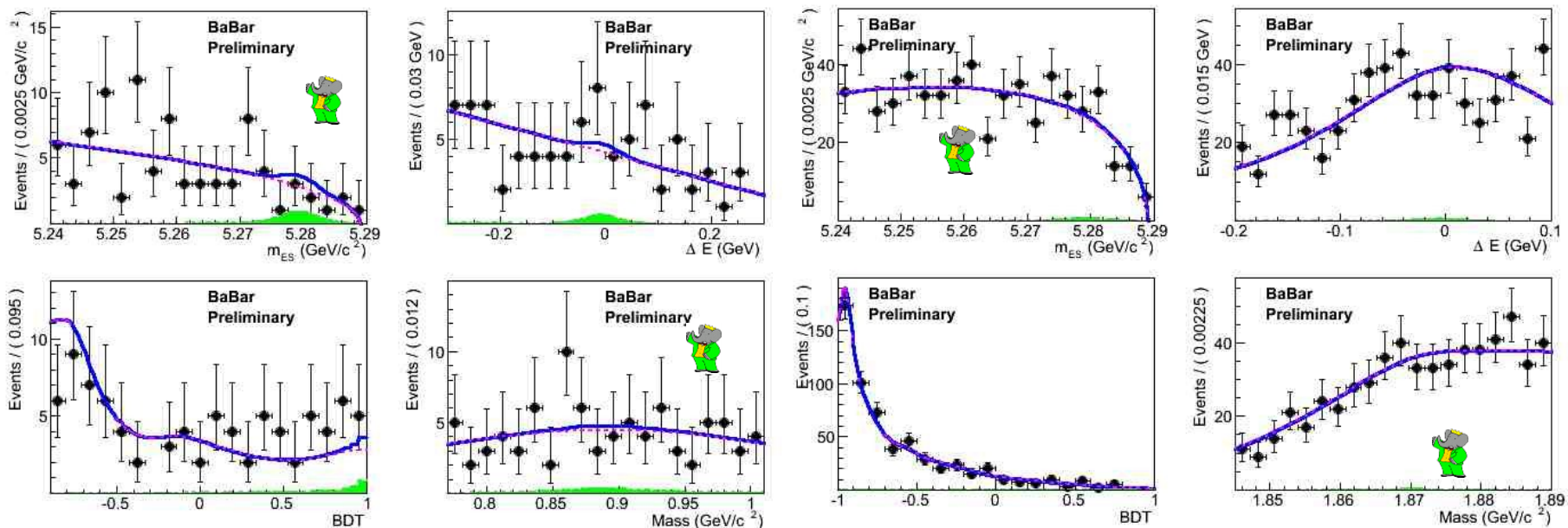
LHCb: PRL 108, 106601 (2012);

PRD 85, 112004 (2012)

$B^+ \rightarrow X^- l^+ l'^+$: Event Selection



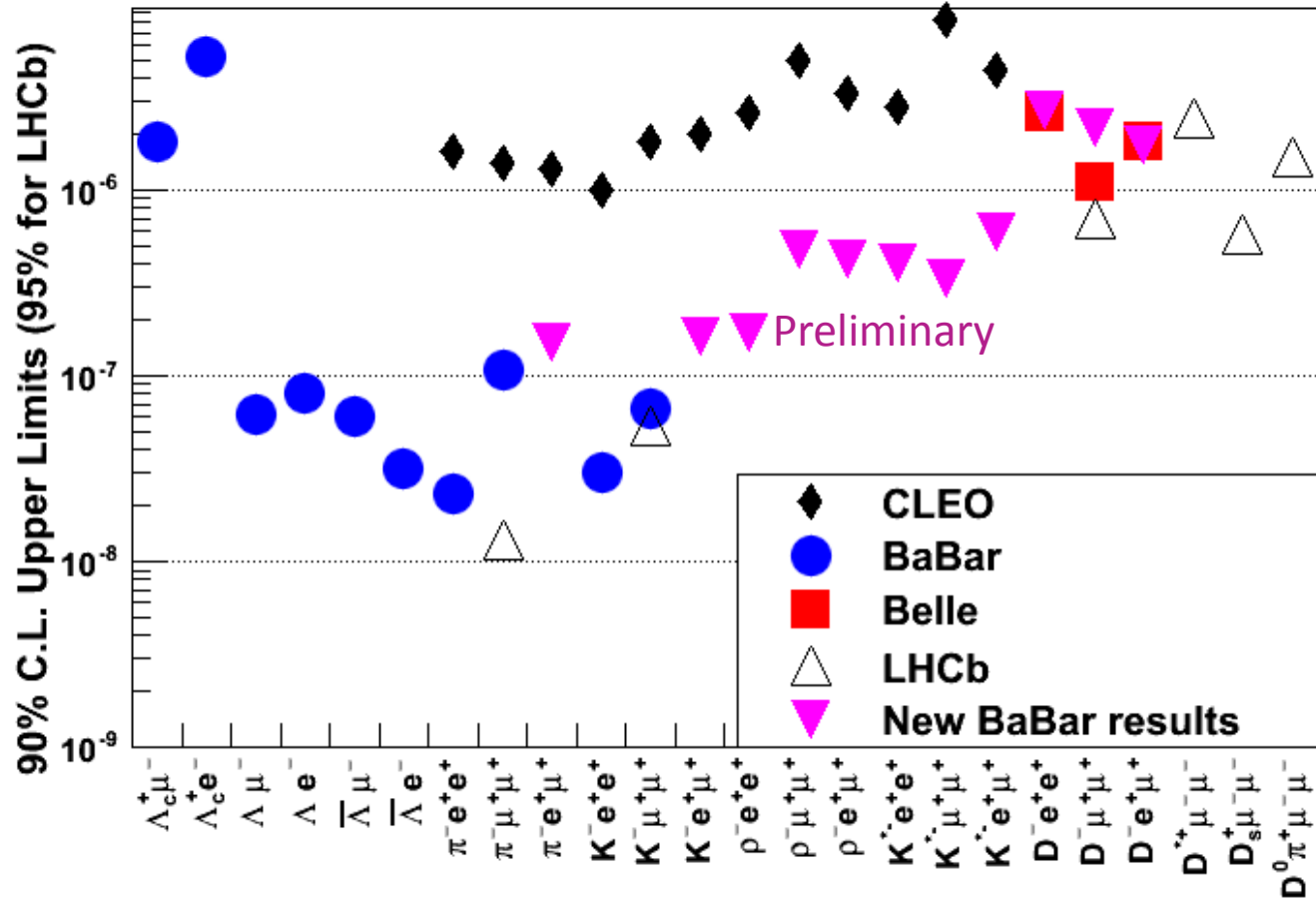
- Reconstruct the 11 modes.
- Construct multivariate discriminant (BDT) to reject backgrounds
- ML fit to 3 or 4 observables: M_{ES} , ΔE , BDT, [$K^*/\rho/D$ mass]:



$$B^+ \rightarrow K^{*-} (\rightarrow K^- \pi^0) \mu^+ \mu^+$$

$$B^+ \rightarrow D^- e^+ \mu^+$$

$B^+ \rightarrow X^- l^+ l'^+$: Preliminary Results



- 11 updated measurements. 90% CL UL in range $(1.5 - 26.4) \times 10^{-7}$
- Order of magnitude improvement for CLEO results.
- Similar precision to Belle for $B^+ \rightarrow D^- l^+ l'^+$

Summary and Conclusion

- Improved A_{cp} for $B \rightarrow X_s \gamma$
 - Compatible with Standard Model.
 - Smaller uncertainties than World Average.
 - First measurement of ΔA_{CP} .
 - To be submitted to PRD.
- Search for $B \rightarrow \pi/\eta l^+ l^-$
 - Upper limits placed on 16 modes.
 - Best limit for $B^0 \rightarrow \pi^0 l^+ l^-$.
 - arXiv:1303.6010
- Search for LNV $B^+ \rightarrow X^- l^+ l'^+$
 - Upper limits place on 11 modes.
 - Order of magnitude improvement compared to CLEO results.
 - Commensurate with Belle results.
 - To be submitted to PRD-RC