Search for Lepton Number Violation in B-meson Decays

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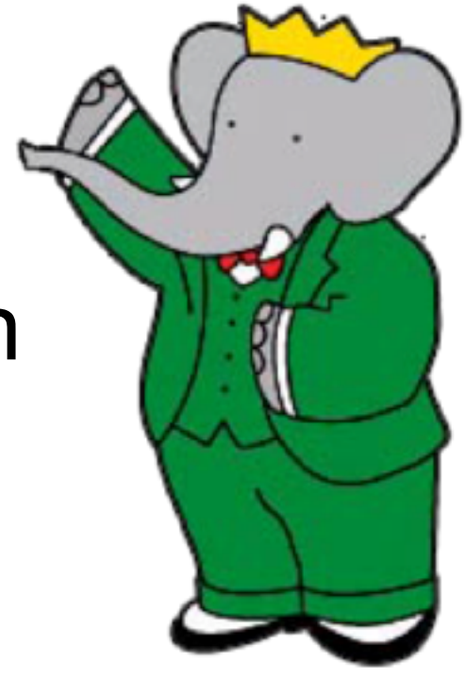
on behalf of the BaBar Collaboration



Outline of talk

- Introducing lepton number violation (LNV), lepton flavour violation (LFV) and baryon number violation (BNV) in B decays
- Analysis techniques
- LNV and BNV in $B^+ \rightarrow \Lambda_{(c)} e^+/\mu^+$
- LNV (and LFV) in $B^+ \rightarrow X^- l^+ l'^+$

Searching for NP in LNV, LFV and BNV decays

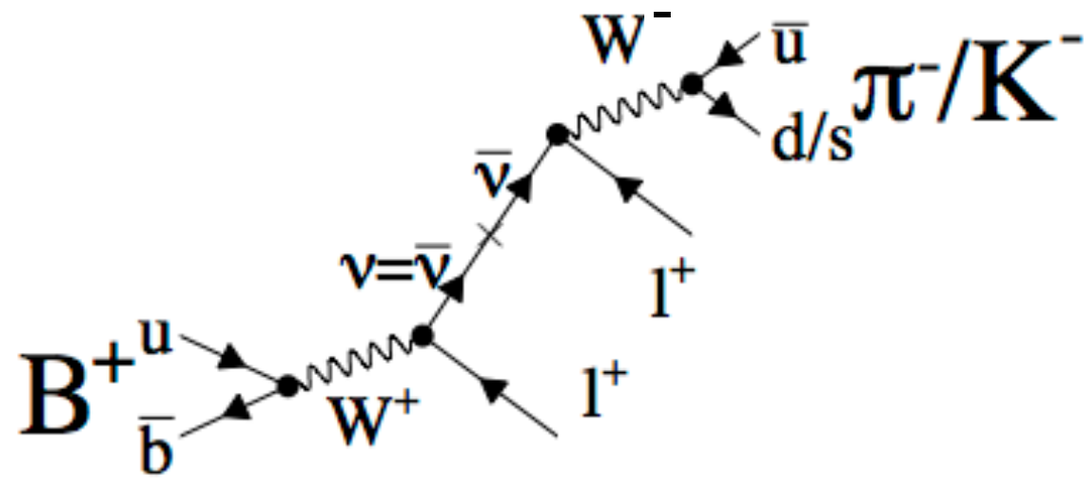
- Neutrino oscillations suggest that lepton number and lepton flavor need not be conserved quantities
  - LFV processes expected to have extremely small unobservable probabilities in SM
- BNV is an essential condition to explain matter/antimatter asymmetry in the Universe
  - Predicted in the SM via non-perturbative processes called sphalerons
  - SM cannot accommodate observed matter/antimatter asymmetry
- LNV predicted in many New Physics models:
  - For example Majorana neutrino exchange [1]
  - SU(5) GUT predict both LNV and BNV [2]
  - Support leptogenesis explanation for the baryon asymmetry in the Universe [3]

[1] A. Atre, T. Han, S. Pascoli and B. Zhang,"The Search for Heavy Majorana Neutrinos", JHEP **0905**, 030 (2009)
[2] H. Georgi and S. L. Glashow,"Unity of All Elementary-Particle Forces",Phys. Rev. Lett. **32**, 438 (1974)
[3] A. Pilaftsis,"The Little Review on Leptogenesis", J. Phys. Conf. Ser. **171** (2009) 012017

LNV in B decays

- Most sensitive searches for LNV involve neutrinoless double beta decay
  - Nuclear environment complicates extraction of neutrino mass scale

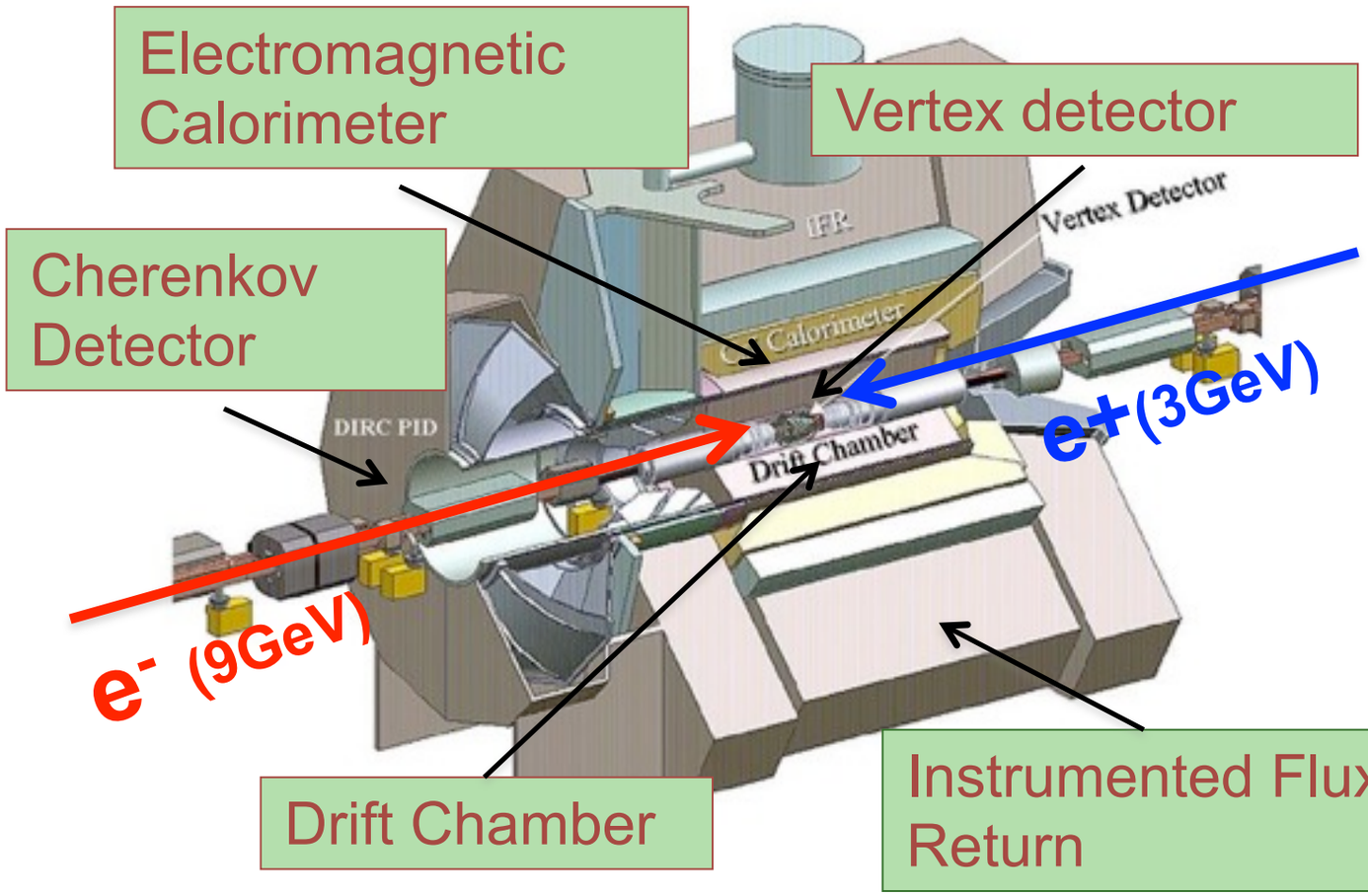
- Alternative approach uses processes involving B meson decays

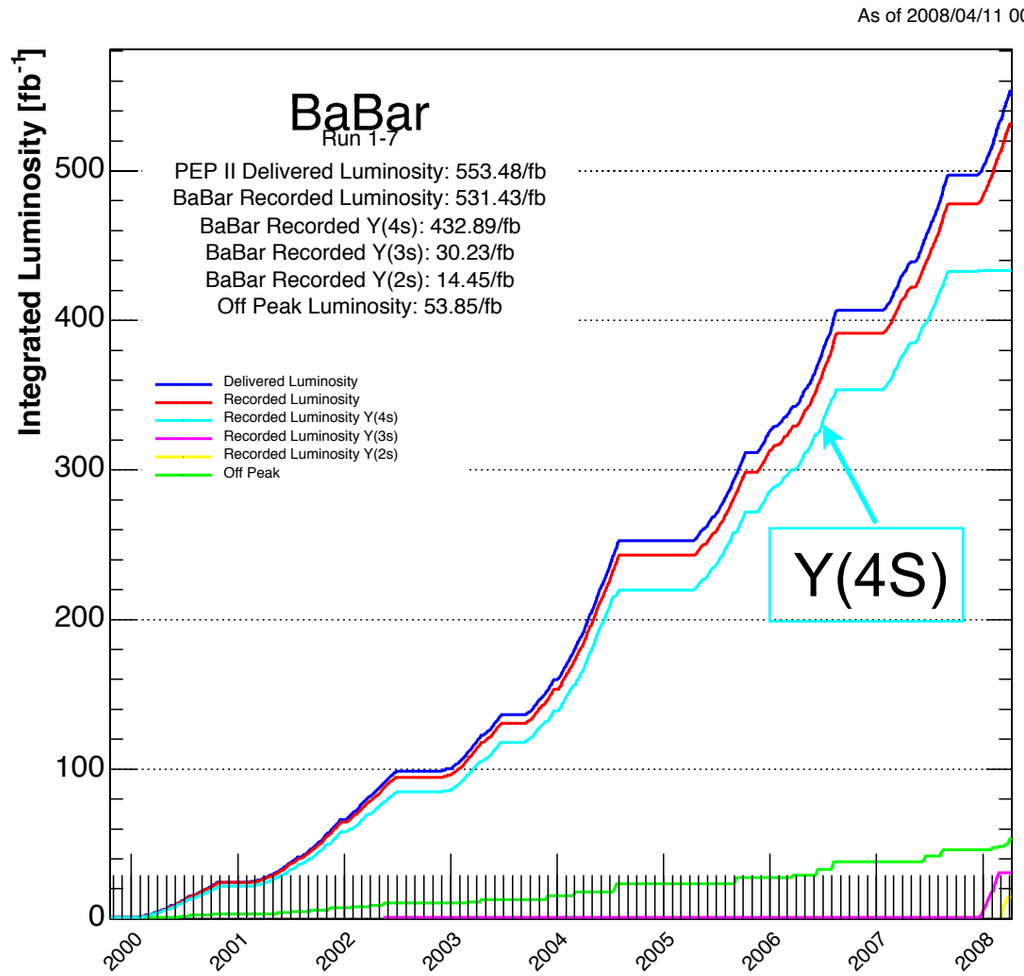


- Measurements of extremely rare B decays improves our sensitivity to physics beyond the SM
- Observation can be a sign of New Physics!

The BaBar detector

- PEP-II B-Factory collided e^+e^- asymmetric beams at Y(4S) energy threshold



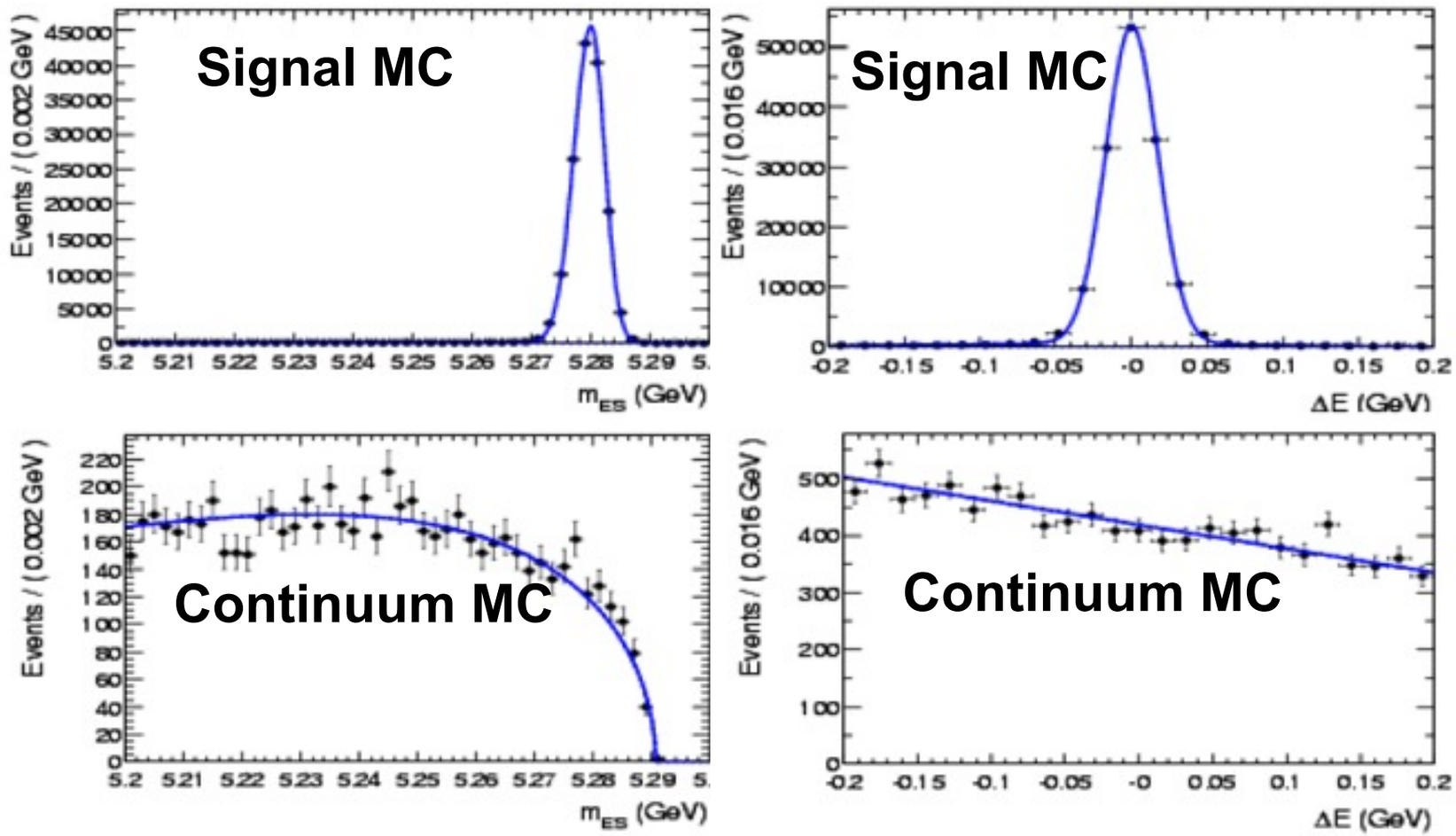


- BaBar in operation from 1999 – 2008
- All analyses presented use full BaBar Y(4S) dataset
  - $432 fb^{-1}$ at the Y(4S)
  - 467M $B\overline{B}$ pairs

Analysis techniques - Kinematics

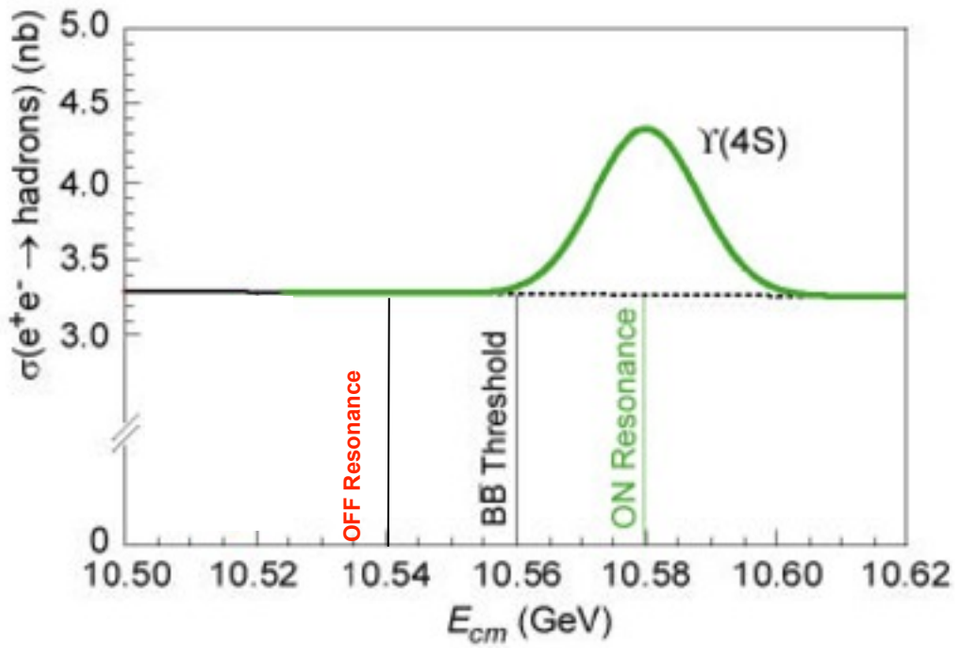
- Use precise kinematical information from beam: m_{ES} and ΔE
- Blind analyses - selection requirements and ML fit tested on MC or data with hidden signal region

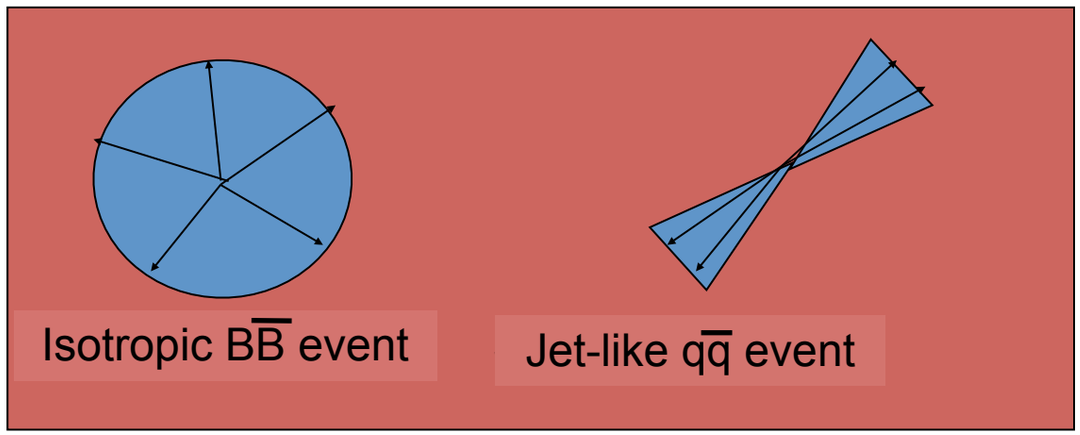
$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}} \qquad \Delta E = E_B^* - E_{beam}^*$$



Analysis techniques - Event topology

- Distinguish light $q\bar{q}$ from $b\bar{b}$ using event topology:
  - B mesons produced almost at rest in the Y(4S) frame – isotropic event topology
  - continuum produced with large kinetic energy – jet-like event topology
    - Combine variables in multivariate discriminant
- Perform maximum likelihood fit that includes signal and background PDFs for m_{ES}, ΔE, and output of multivariate discriminant





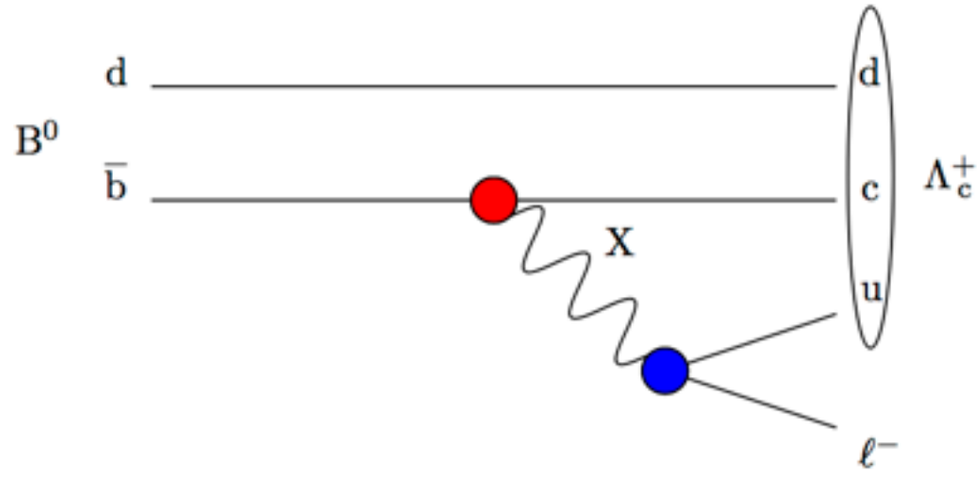
Outline

- Introducing lepton number violation (LNV), lepton flavour violation (LFV) and baryon number violation (BNV) in B decays
- Analysis techniques and dataset
- LNV and BNV in $B^+ \to \Lambda_{(c)} e^+/\mu^+$
- LNV in $B^+ \to X^- l^+ l'^+$

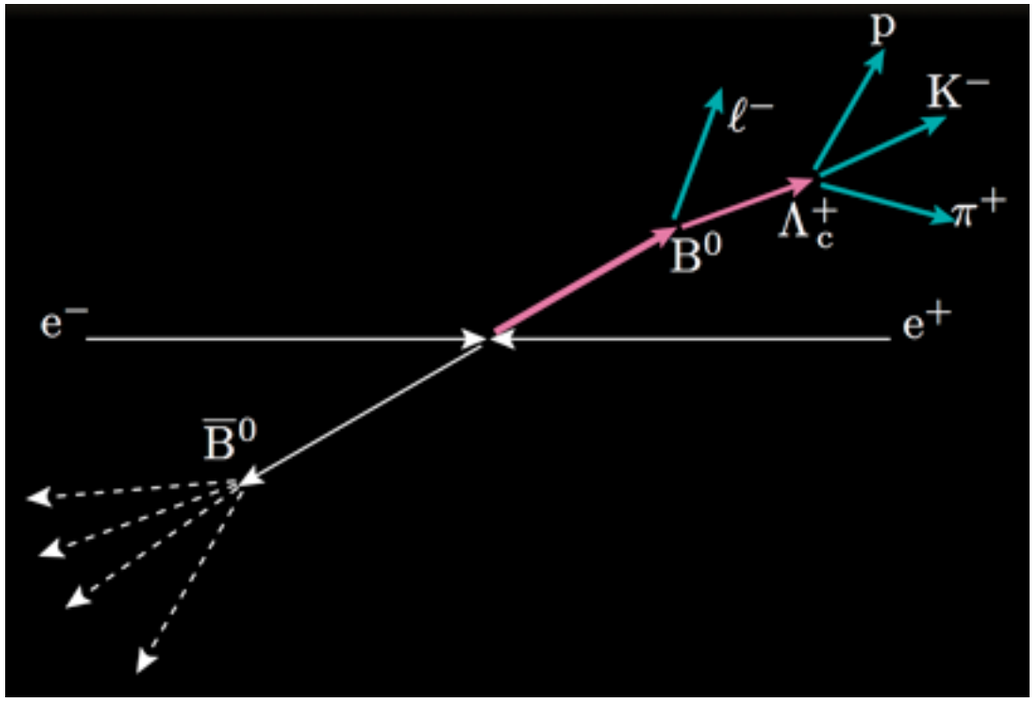
LNV in $B^{+(0)} \to \Lambda_{(c)} e^+/\mu^+$: Analysis

PRD 83, 091101 (2011)

- Not only LNV but also BNV
- First and only measurement of these decay modes
- Reconstruct $\Lambda_c \to pK^-\pi^+$ (BF = 5%) and $\Lambda \to p\pi^-$ (BF = 64%) originating from common vertex with a lepton



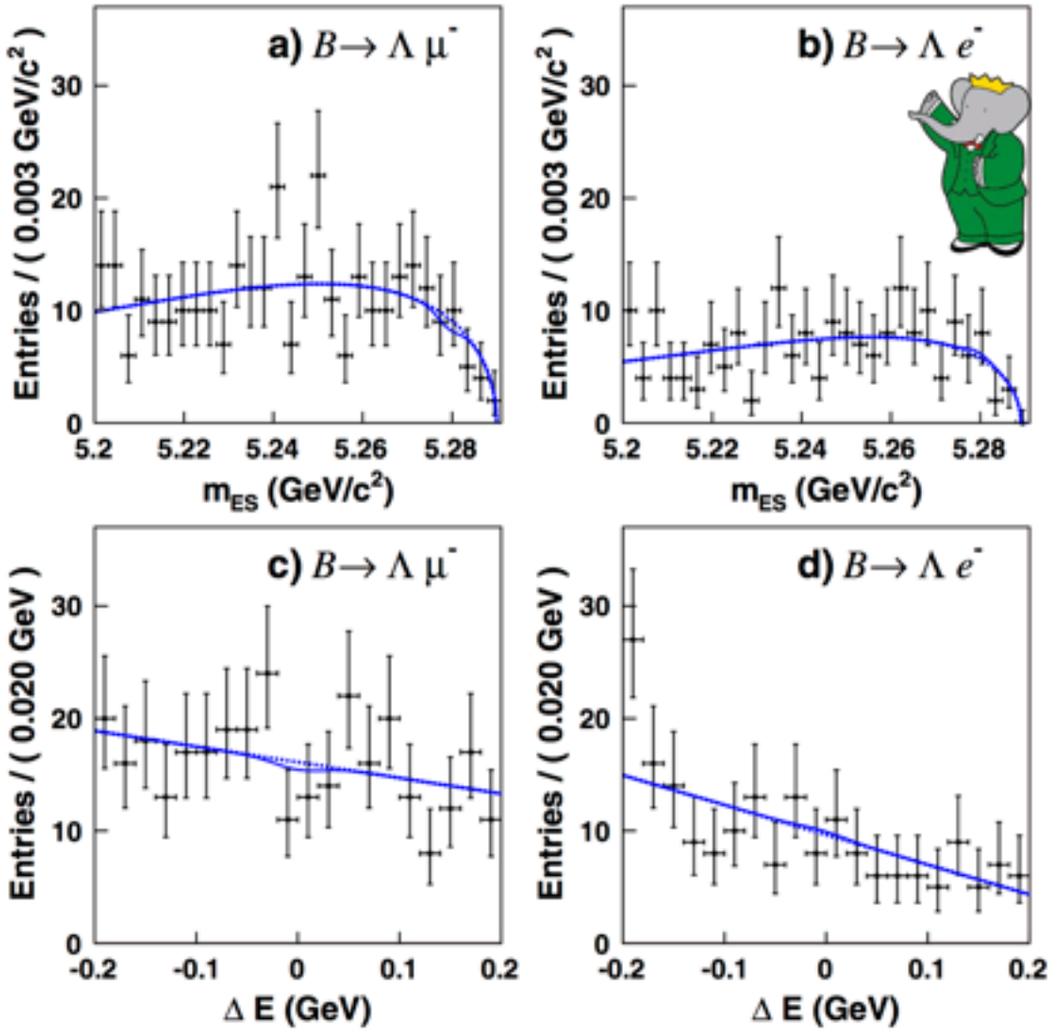
- Require more than four charged-particle tracks to reduce $e^+e^- \to e^+e^-\gamma$ background
- Construct neural network from six event-shape variables



LNV in $B^{+(0)} \to \Lambda_{(c)} e^+/\mu^+$: Results

PRD 83, 091101 (2011)

- Signal region defined as:
  - $5.2 < m_{ES} < 5.289$ GeV/c^2
  - $|\Delta E| < 0.2$ GeV
- Signal m_{ES} and ΔE PDF modeled via Crystal Ball function;
- NN_{out} modeled via nonparametric PDF
- No significant signal observed
  - Branching fraction upper limits range between (3-180)×10^{-8}



Decay Mode	N_{cand}	$\mathcal{B}(\times 10^{-8})$	$\epsilon(\%)$	$\mathcal{B}_{90\%}(\times 10^{-8})$
$B^0 \to \Lambda_c^+ \mu^-$	814	-4^{+71}_{-56}	26.3 ± 0.9	180
$B^0 \to \Lambda_c^+ e^-$	651	190^{+130}_{-90}	25.7 ± 0.7	520
$B^- \to \Lambda \mu^-$	320	$-2.3^{+3.5}_{-2.5}$	28.7 ± 0.9	6.2
$B^- \to \Lambda e^-$	194	$1.2^{+3.7}_{-2.6}$	27.2 ± 0.6	8.1
$B^- \to \bar{\Lambda} \mu^-$	192	$1.5^{+2.6}_{-1.7}$	31.3 ± 1.0	6.1
$B^- \to \bar{\Lambda} e^-$	74	$-0.9^{+0.7}_{-0.0}$	30.0 ± 0.6	3.2

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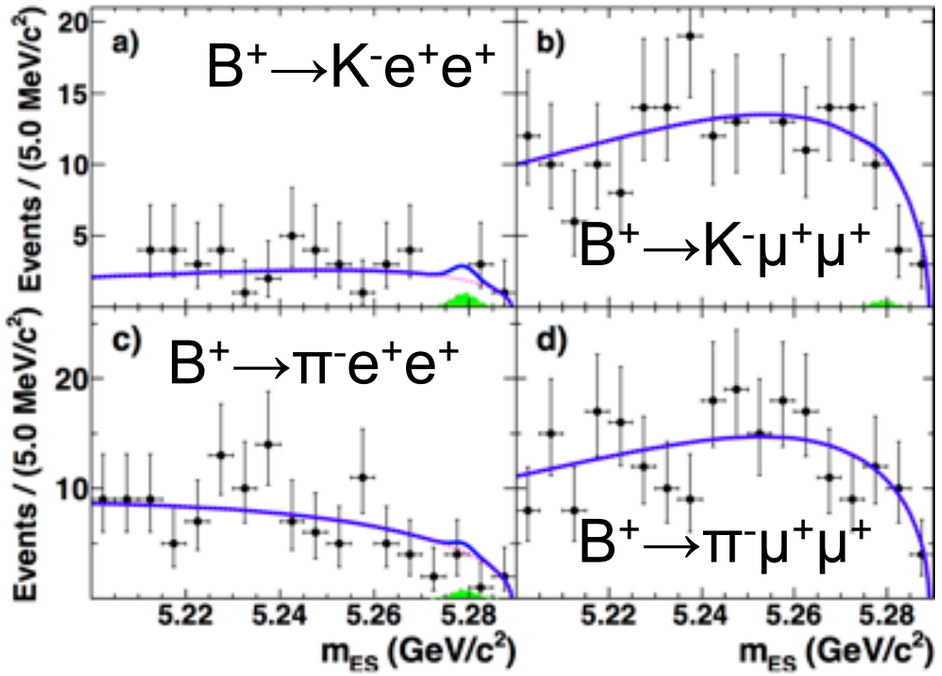
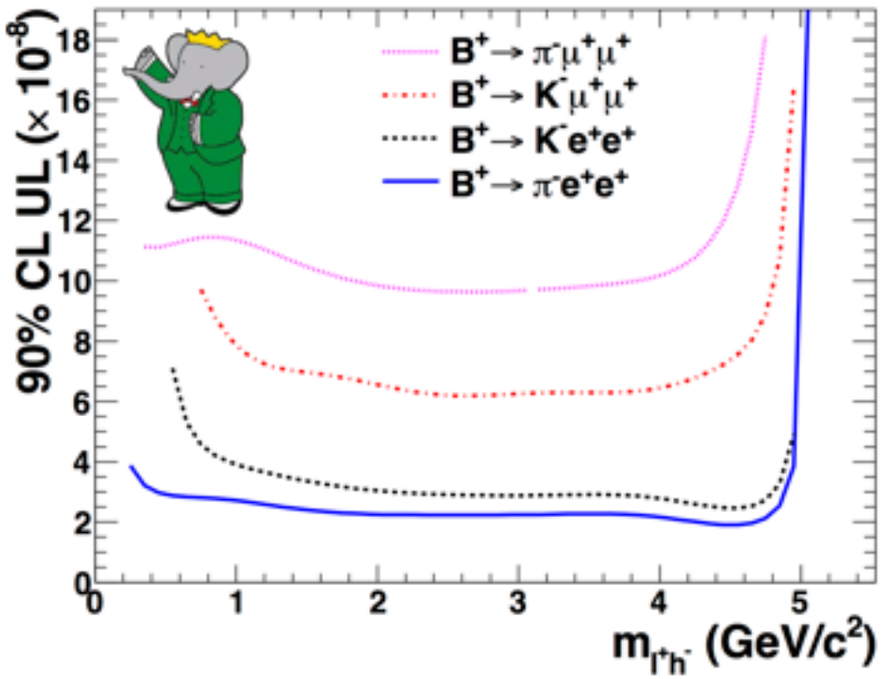
LNV in $B^+ \to K^-(\pi^-)\mu^+\mu^+$ and $B^+ \to K^-(\pi^-)e^+e^+$

PRD 85, 071103 (2012)

- Decay mechanism topologically similar to $0\nu\beta\beta$ decays.
- Select events with four charged-particle tracks and same-sign charged leptons from a single vertex
- Apply a veto for J/ψ and ψ(2S) mass range
- 18 event shape variables in Boosted Decision Tree
- Signal m_{ES} distribution parametrised using Gaussian mean and width from a fit to similar final state $B^+ \to J/\psi(\to l^+l^-)h^+$
- No significant signal found
  - BF upper limits of order 10^{-8}

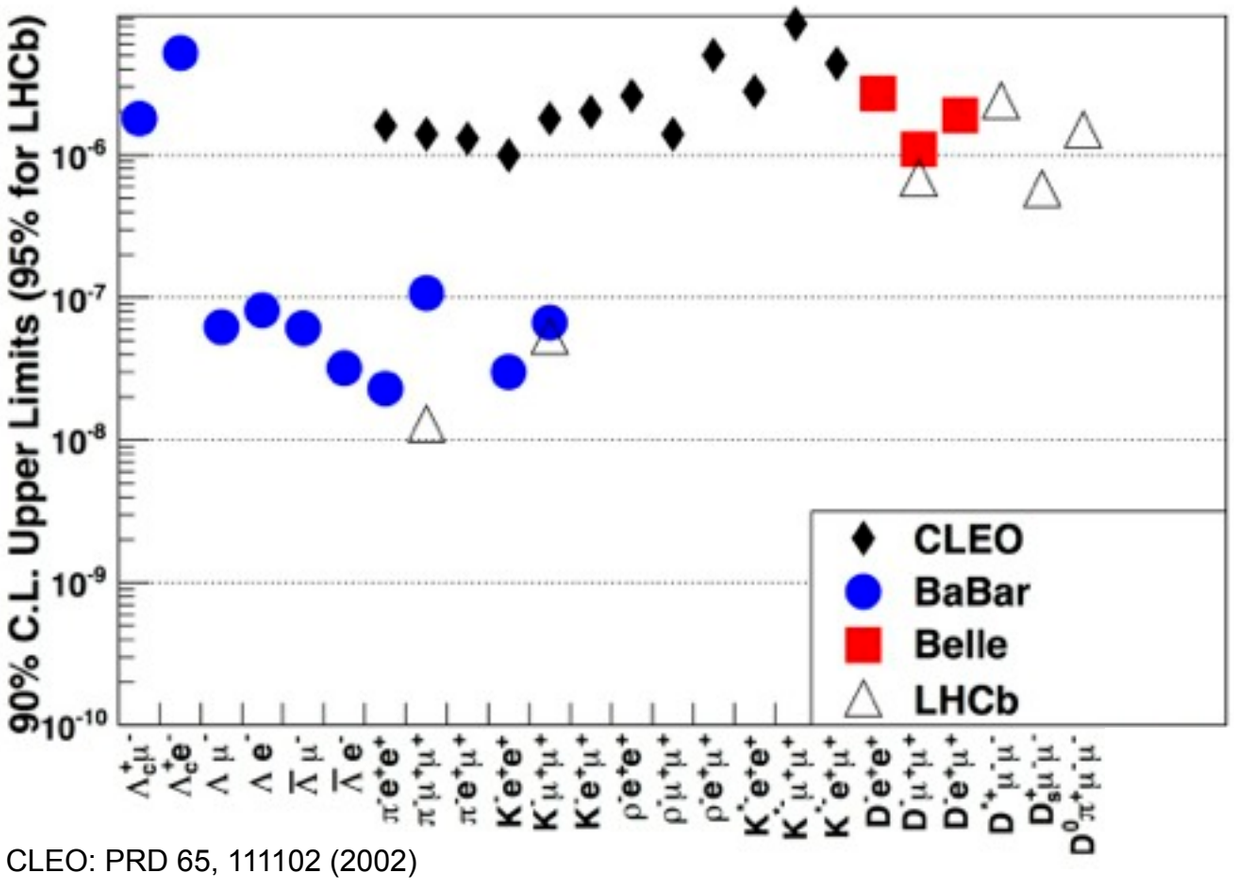




LNV in $B^+ \to X^- l^+ l'^+$: Introduction

To be submitted to PRD

- Searching for 11 modes:
  - $B^+ \to \rho^- l^+ l'^+$
  - $B^+ \to K^{*-}(\to K_S^0 \pi^-$ and $\to K^- \pi^0) l^+ l'^+$
  - $B^+ \to D^-(\to K^- \pi^- \pi^+) l^+ l'^+$
  - $B^+ \to K^-(\pi^-) e^+ \mu^+$
- $B^+ \to X^- e^+ \mu^+$ both LNV and LFV
- Some decay modes not measured since CLEO
- CLEO searches found upper limits on branching fractions in ranges $(1.0\text{-}8.3) \times 10^{-6}$ at 90% CL



CLEO: PRD 65, 111102 (2002)
Belle: PRD 8
PF
BaBar: PRD
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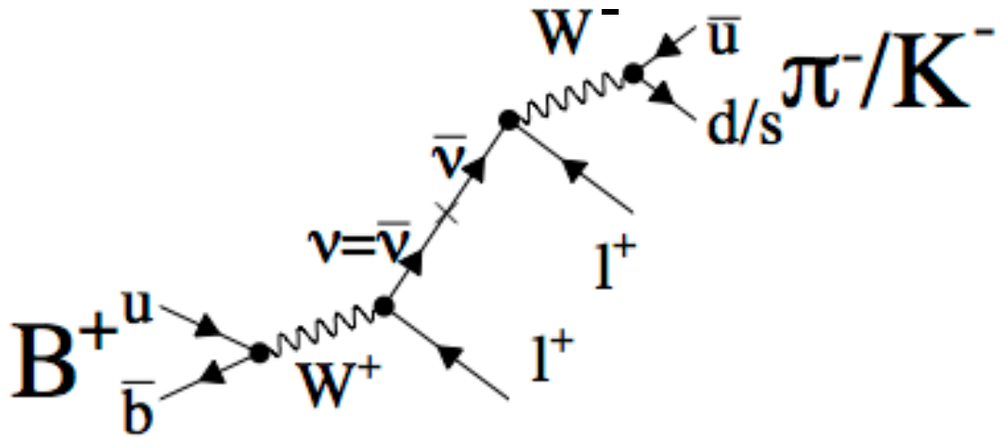
LHCb: PRL 1
PRI

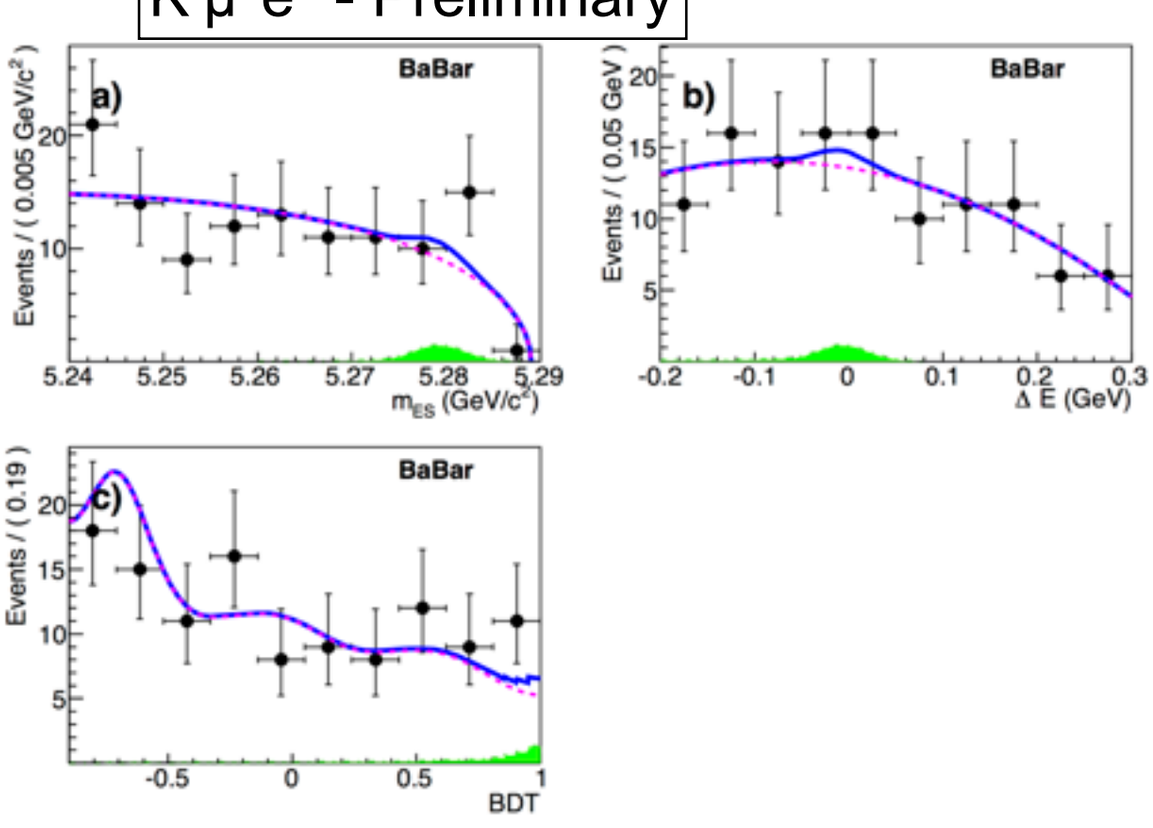


LNV in $B^+ \to X^- l^+ l'^+$: Analysis

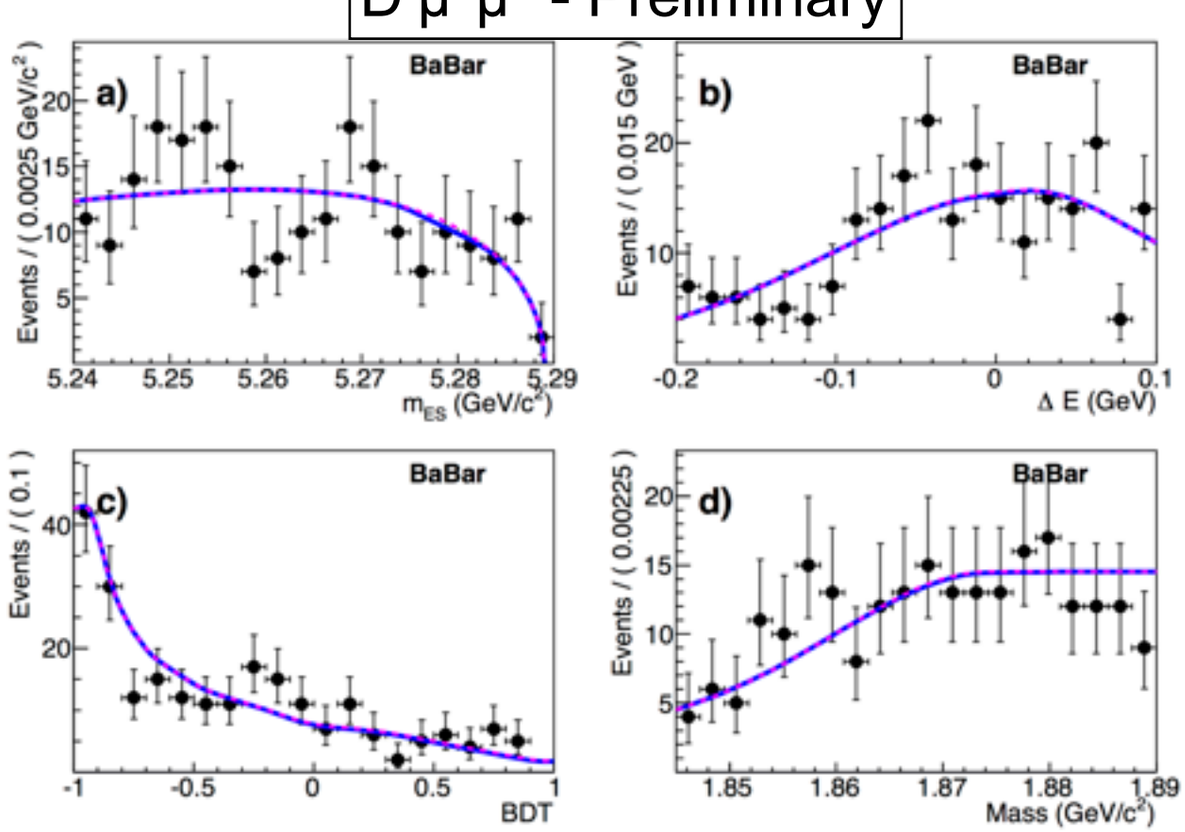
To be submitted to PRD

- Signal m_{ES} and ΔE PDFs modeled with Crystal Ball function
- Boosted Decision Tree includes 9 event shape variable inputs and fitted using a non-parametric KEYS function
- Invariant masses modeled with two Gaussians, Breit-Wigner and Gounaris-Sakurai function for D^-, K^{*-} and ρ^- respectively

$K^-\mu^+e^+$ - Preliminary



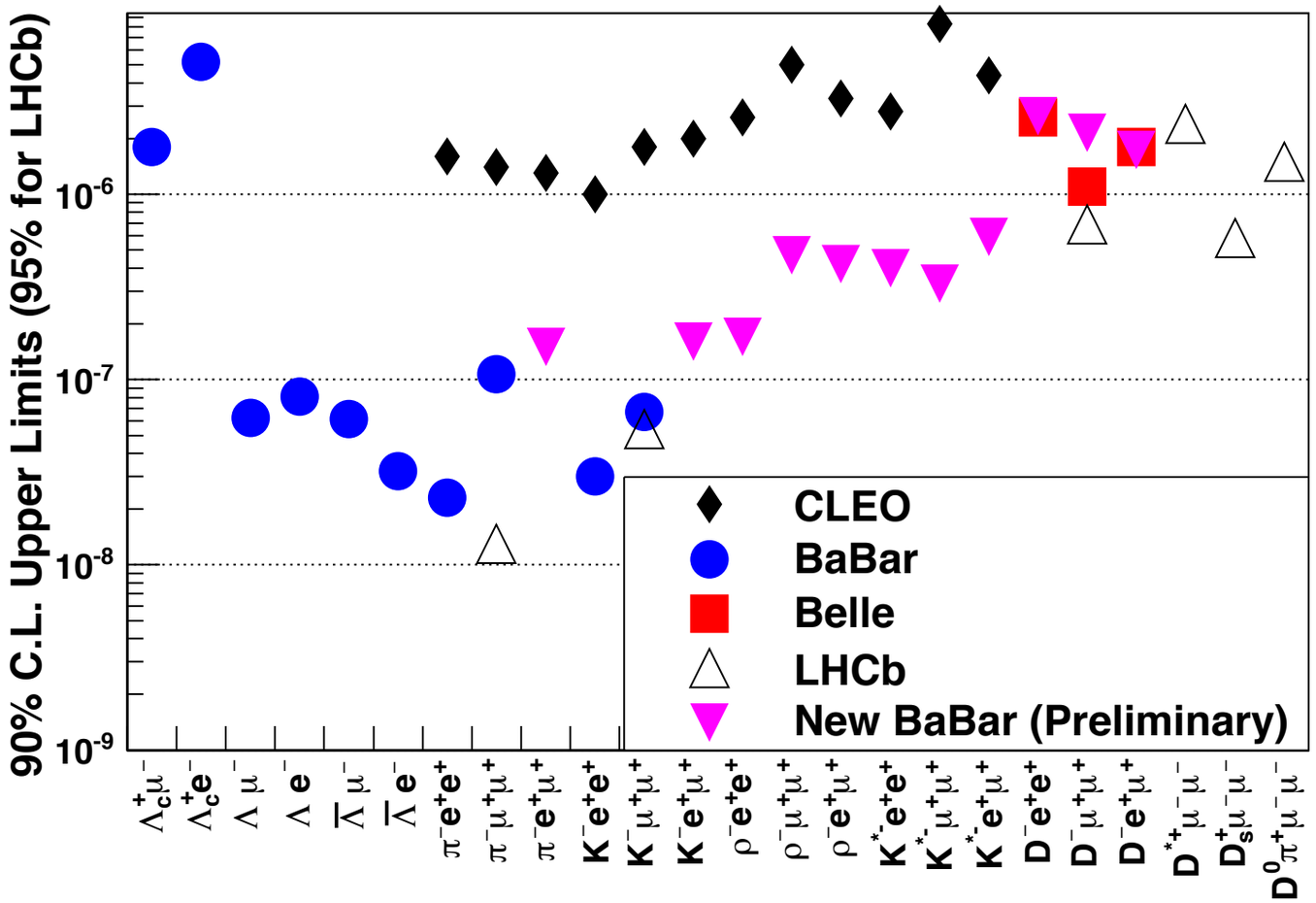
$D^-\mu^+\mu^+$ - Preliminary



LNV in $B^+ \to X^- l^+ l'^+$: Results

To be submitted to PRD

- No significant signal found
- BF upper limits found in range $(15\text{-}264)\times10^{-8}$
- Good agreement in the upper limits with BaBar and Belle results for $B^+ \to D^- l^+ l'^+$
- More stringent limits on π, ρ, K and K* modes
  - π, ρ, K upper limits an order of magnitude more stringent a previous measurements



Conclusion

- BaBar has searched for many LNV and BNV B decays
- No significant signal is found in any channel
  - BF upper limits set on all decay modes at 90% CL
  - Best sensitivity ~10^{-8}
  - New results give more stringent upper limits on most decay modes
- Higher statistics in the search for these extremely rare decays does not automatically lead to higher efficiencies
  - Increase in the background level can mean efficiency is the same
  - Higher luminosity experiments like Belle-II or future LHCb measurements can increase sensitivity to these decays
- Some future experiments are specifically designed to search for LNV and LFV e.g. Mu2e experiment at Fermilab and neutrinoless double beta decay experiments

Back-up

LNV in $B^+ \to K^-(\pi^-)\mu^+\mu^+$ and $B^+ \to K^-(\pi^-)e^+e^+$: Results

Mode	Events	Fit Bias	Yield	η (%)	$\mathcal{S}$ (σ)	$\mathcal{B}$ ($\times 10^{-8}$)	$\mathcal{B}_{UL}$ ($\times 10^{-8}$)
$B^+ \to \pi^- e^+ e^+$	123	$+0.15 \pm 0.09$	$0.6^{+2.5}_{-2.7}$	47.8 ± 0.1	0.4	$0.27^{+1.1}_{-1.2} \pm 0.1$	2.3
$B^+ \to K^- e^+ e^+$	42	-0.30 ± 0.15	$0.7^{+1.8}_{-1.2}$	30.9 ± 0.1	0.5	$0.49^{+1.3}_{-0.8} \pm 0.1$	3.0
$B^+ \to \pi^- \mu^+ \mu^+$	228	-0.01 ± 0.05	$0.0^{+3.2}_{-2.0}$	13.1 ± 0.1	0.0	$0.03^{+5.1}_{-3.2} \pm 0.6$	10.7
$B^+ \to K^- \mu^+ \mu^+$	209	$+0.02 \pm 0.04$	$0.5^{+3.5}_{-2.5}$	23.0 ± 0.1	0.2	$0.45^{+3.2}_{-2.7} \pm 0.4$	6.7

LNV in $B^+ \to X^- l^+ l'^+$: Results

Mode	Events	Yield	$\epsilon(\%)$	$\Pi\mathcal{B}_i(\%)$	S(σ)	$\mathcal{B}$ ($\times 10^{-8}$)	$\mathcal{B}_{UL}$ ($\times 10^{-8}$)
$B^+ \to K^{*-}\, e^+\, e^+$					1.2	$17 \pm 14 \pm 1.4$	40
$K^{*-} \to K^- \pi^0$	63	3.8 ± 3.3	11.5 ± 0.1	33.3	1.2	$21 \pm 18 \pm 1.5$	51
$K^{*-} \to K^0_S\, \pi^-$	91	0.8 ± 3.9	12.3 ± 0.1	22.8	0.3	$6.1 \pm 29 \pm 1.6$	60
$B^+ \to K^{*-}\, e^+\, \mu^+$					0.0	$-49 \pm 28 \pm 4$	33
$K^{*-} \to K^- \pi^0$	117	-1.9 ± 4.7	7.9 ± 0.1	33.3	0.0	$-15 \pm 38 \pm 4$	65
$K^{*-} \to K^0_S\, \pi^-$	172	-13.4 ± 3.5	8.5 ± 0.1	22.8	0.0	$-92 \pm 36 \pm 7$	49
$B^+ \to K^{*-}\, \mu^+\, \mu^+$					1.3	$24 \pm 18 \pm 4$	59
$K^{*-} \to K^- \pi^0$	85	2.3 ± 1.8	6.1 ± 0.1	33.3	1.5	$20 \pm 18 \pm 2$	70
$K^{*-} \to K^0_S\, \pi^-$	98	2.0 ± 2.3	5.8 ± 0.1	22.8	1.9	$31 \pm 29 \pm 9$	98
$B^+ \to \rho^- e^+ e^+$	411	-2.1 ± 5.7	12.1 ± 0.1	100.0	0.0	$-3.8 \pm 10 \pm 1.2$	17
$B^+ \to \rho^- e^+ \mu^+$	1651	4.6 ± 11.4	10.3 ± 0.1	100.0	0.4	$9.6 \pm 24 \pm 2.4$	47
$B^+ \to \rho^- \mu^+ \mu^+$	936	2.9 ± 6.8	7.3 ± 0.1	100.0	0.5	$8.5 \pm 20 \pm 2.6$	42
$B^+ \to D^- e^+ e^+$	401	3.9 ± 4.8	10.2 ± 0.1	9.13	1.0	$88 \pm 86 \pm 15$	264
$B^+ \to D^- e^+ \mu^+$	549	1.1 ± 3.2	7.7 ± 0.1	9.13	0.5	$34 \pm 94 \pm 11$	215
$B^+ \to D^- \mu^+ \mu^+$	229	-1.7 ± 2.5	5.7 ± 0.1	9.13	0.0	$-65 \pm 99 \pm 9$	174
$B^+ \to K^- e^+ \mu^+$	117	5.5 ± 3.5	15.2 ± 0.1	100.0	1.8	$6.0 \pm 4.9 \pm 0.9$	16
$B^+ \to \pi^- e^+ \mu^+$	464	3.8 ± 3.5	16.4 ± 0.2	100.0	1.2	$4.9 \pm 4.5 \pm 0.3$	15