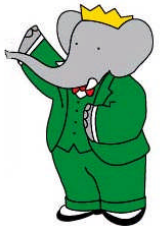
Exotic, LFV and LNV decays at B factories



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Outline of the talk

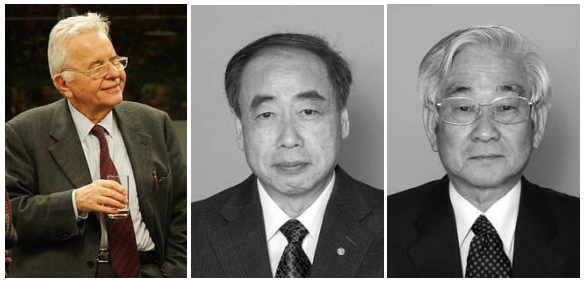
Where to look for New Physics at the low energy?

Processes very suppressed or even forbidden

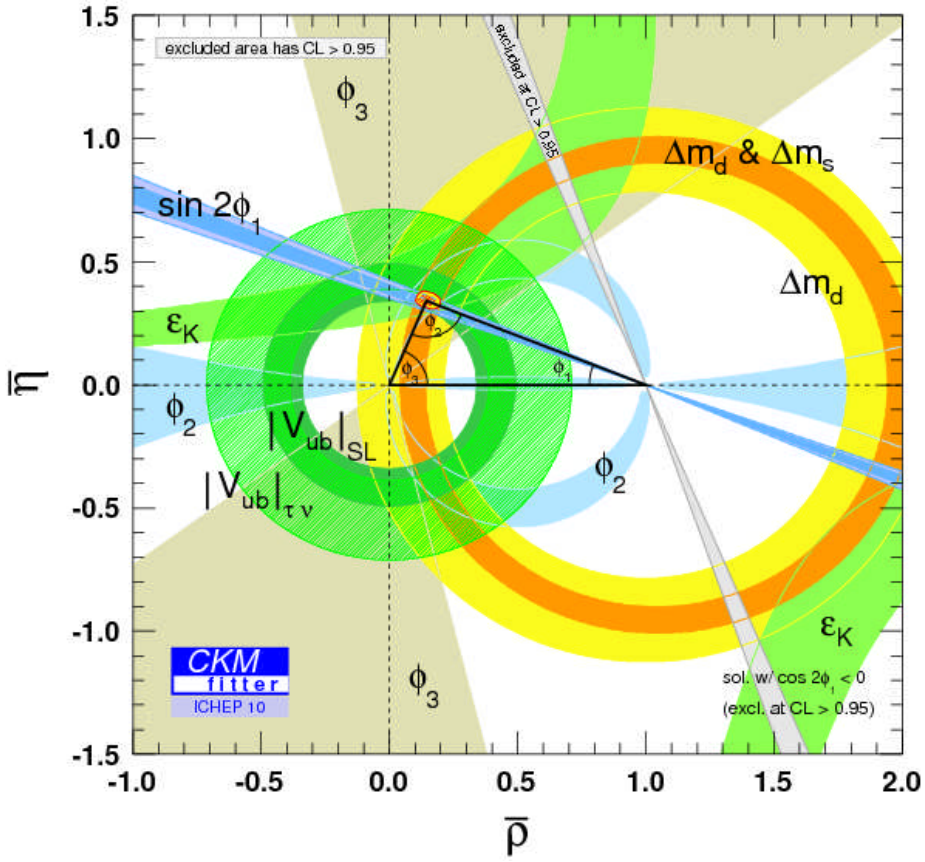
- Introduction
- Dataset
- Search for
  - ❑ $B \rightarrow \gamma\gamma$, $D\ell\ell'$, $\ell\ell'$
  - ❑ $D \rightarrow \ell\ell'$
  - ❑ LFV in τ decays
- Closing remarks

Moving from one phase to another

- Belle and BABAR have played an important role on verifying the CKM framework for CPV in the SM

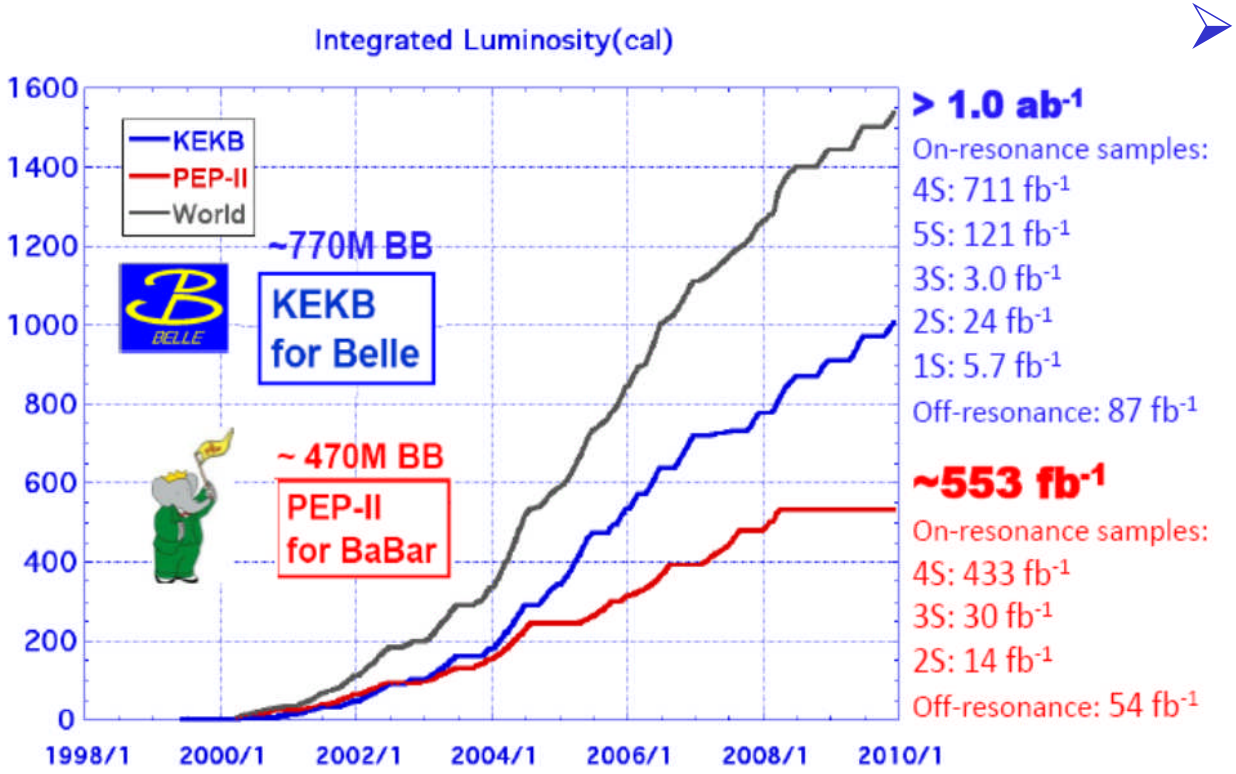


- Focus is now geared toward an intensive search for the new physics ➡ complementary to the energy frontiers (Tevatron and LHC)



Status of the unitarity triangle (presented at ICHEP10, Paris)

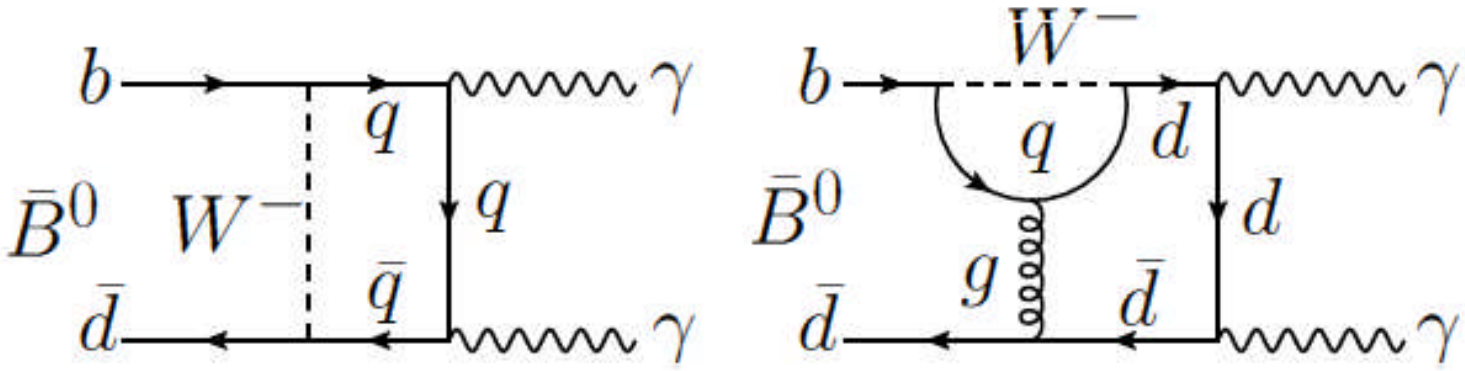
What about the data size?



- The two experiments have collected a large sample of
  - $B\bar{B}$ pairs
  - D mesons
  - $e^+e^- \rightarrow \tau^+\tau^-$
  - other $\Upsilon(nS)$

- Allows us to look for various exotic, including LFV and LNV, decays of B, D mesons and τ lepton

Search for the decay $B^0 \to \gamma\gamma$



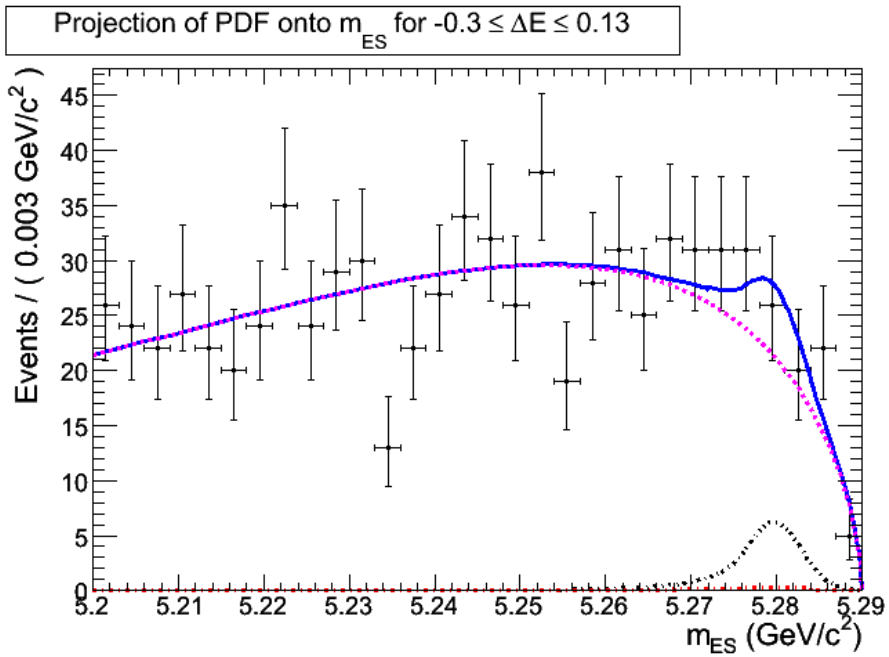
- Flavor changing neutral current (FCNC) transition involving electroweak loop diagrams
- B^0 decay is suppressed by $|V_{td}/V_{ts}|^2$ ($\approx 4\%$) with respect to that of B_S (replace *d* with *s* quark)
- SM prediction for branching fraction $\left(3.1^{+6.4}_{-1.6}\right) \times 10^{-8}$ **JHEP 0208:054 (2002)**
- New physics scenarios, *e.g.*, extended Higgs sector or SUSY with broken *R*-parity can significantly enhance the BF **PRD 58, 095014 (1998)** **PRD 70, 035008 (2004)**

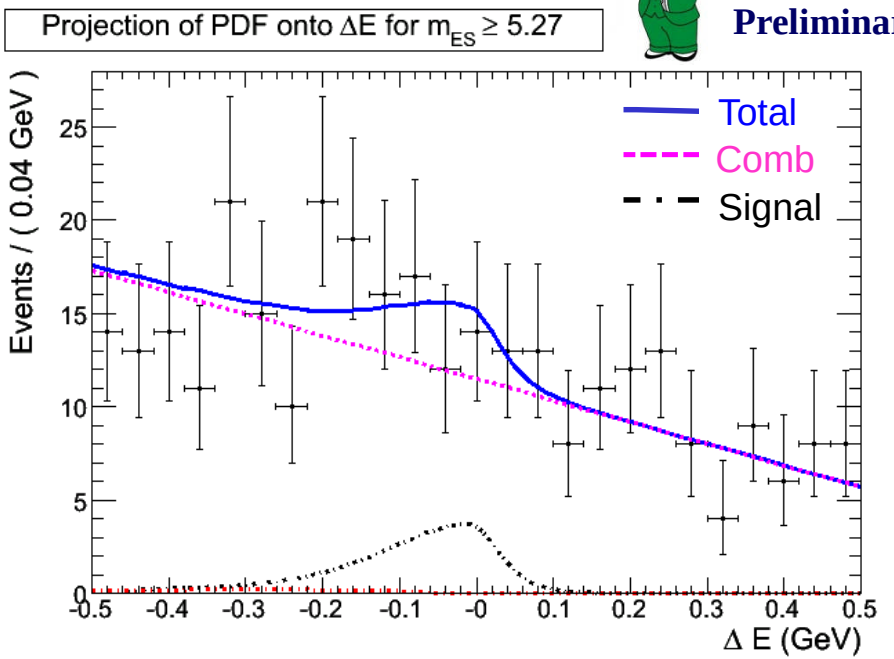
Recent results from BaBar

- Signal yield extracted from a 2D unbinned maximum likelihood fit to m_{ES} and ΔE

$$N_{\rm sig} = 21.3^{+12.8}_{-11.8} \pm 1.4$$

- 90% CL upper limit $\mathcal{B}(B^0 \to \gamma\gamma) < 3.2 \times 10^{-7}$





Preliminary

What the future holds?

- Slowly inching towards the SM value: constraints on NP models

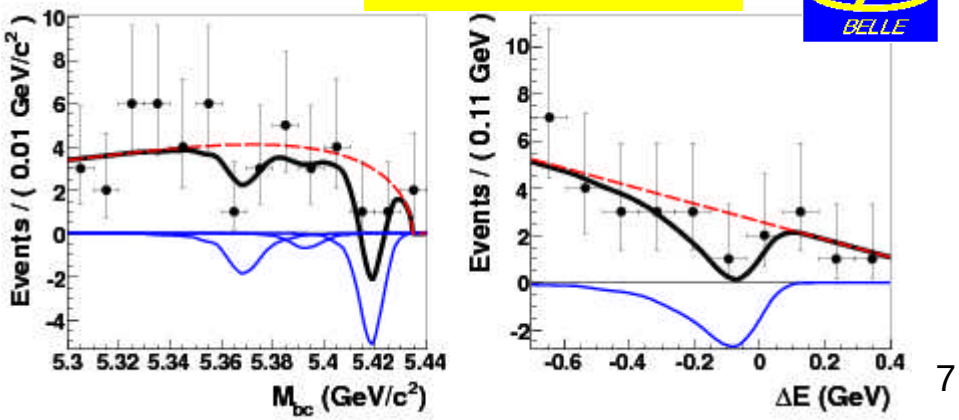
Experiment	BF (90% CL)	Dataset	Reference
BaBar	$< 1.7 \times 10^{-6}$	$19\,\text{fb}^{-1}$	PRL 87, 24 (2001)
Belle	$< 6.1 \times 10^{-7}$	$104\,\text{fb}^{-1}$	PRD 73, 051107 (2006)
BaBar	$< 3.2 \times 10^{-7}$	$426\,\text{fb}^{-1}$	Prelim. @ ICHEP2010

- With the Belle full $\Upsilon(4S)$ dataset (711 fb^{-1}), we will be even closer to an observation

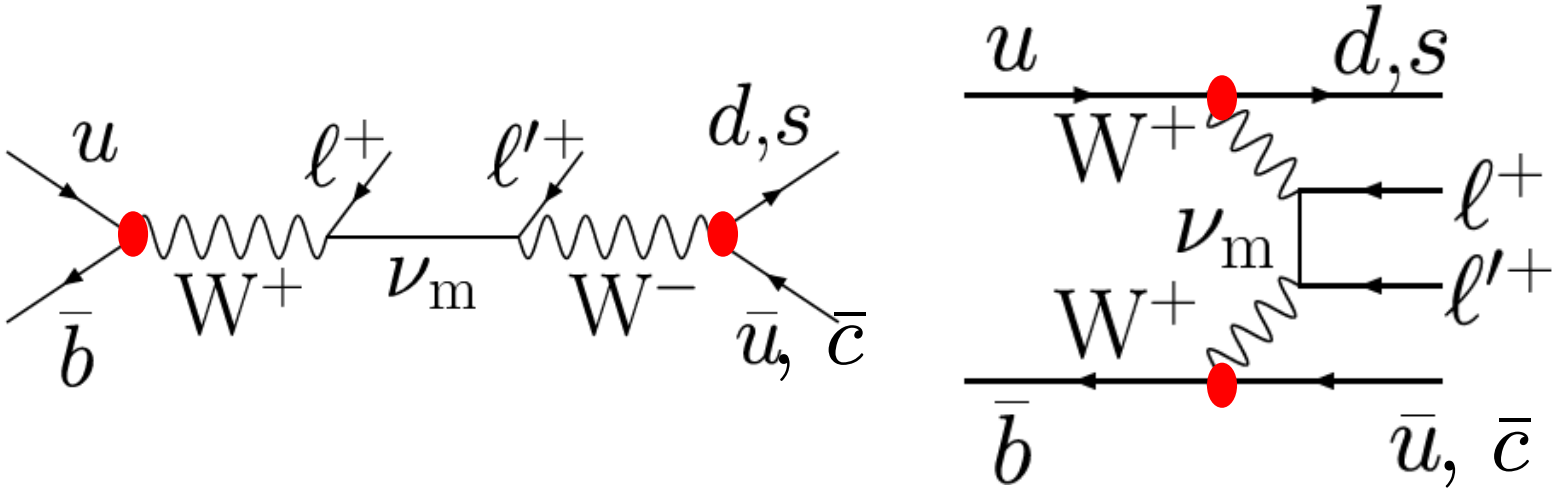
- Belle has also provided a first upper limit on the BF for $B_S \to \gamma\gamma$ (8.7×10^{-6}) using 23.6 fb^{-1} $\Upsilon(5S)$ data

- Will be interesting to see this number with the full $\Upsilon(5S)$ data (121 fb^{-1})

P RL 100, 121801 (2008)



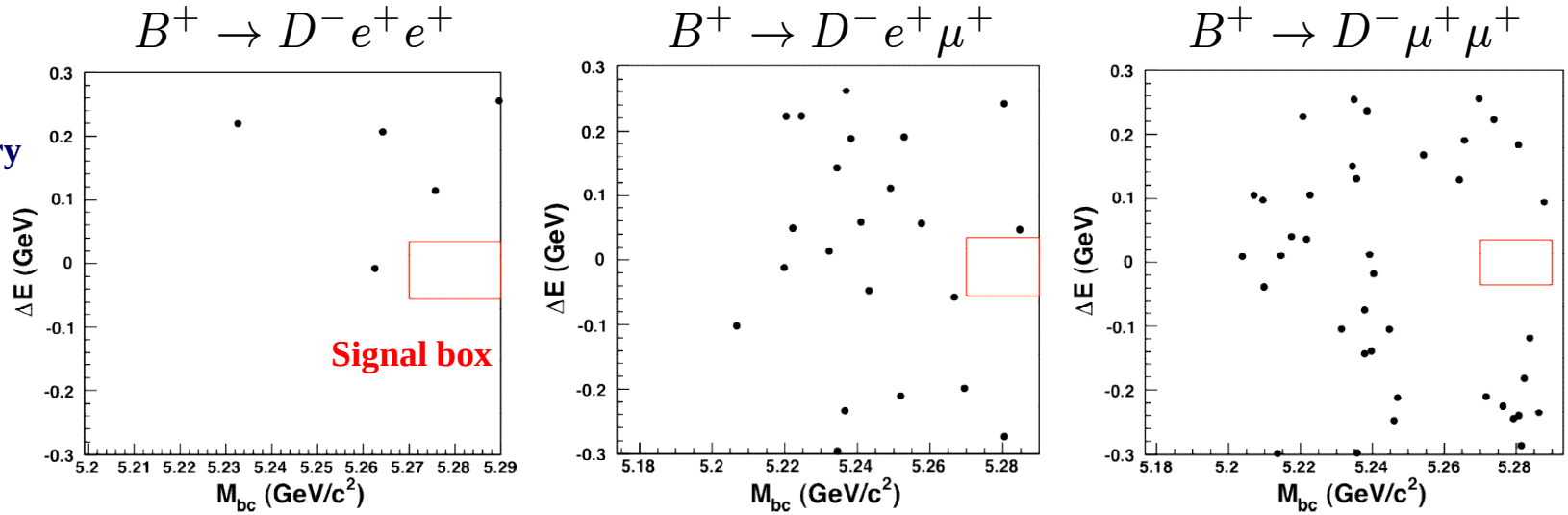
Search for $B^+ \to D^-\ell^+\ell'^+$



- Both lepton flavor violating (LFV) and lepton number violating (LNV) decay, involving Majorana ν's ➡ strongly suppressed in the SM
- Due to the size of the CKM matrix elements involved, the $B^+ \to D^-\ell^+\ell'^+$ decay will be the most sensitive
- Belle has performed a first search of the decay, where the D^+ decays to $K^-\pi^+\pi^+$, using 770×10^6 $B\bar{B}$ decays

Recent results from Belle

Preliminary



- Blind, counting analysis after a likelihood (based on event shape variables) is employed to suppress contribution from the $e^+e^- \to q\bar{q}$ continuum background
- No evidence for a signal ➡ derive 90% CL upper limits on BF

Decay mode	Eff.	$N_{\rm bkg}$	UL on BF
$B^+ \to D^- e^+ e^+$	1.2%	0.18 ± 0.13	2.7×10^{-6}
$B^+ \to D^- e^+ \mu^+$	1.3%	0.83 ± 0.29	1.9×10^{-6}
$B^+ \to D^- \mu^+ \mu^+$	1.8%	1.44 ± 0.43	1.1×10^{-6}

What about other channels?

- Results are from CLEO (BaBar) with 9.6 (230)×10^6 $B\bar{B}$ decays

- Belle plans to extend search to other LFV, LNV B decays

CLEO PRD 65, 111102(R) (2002)

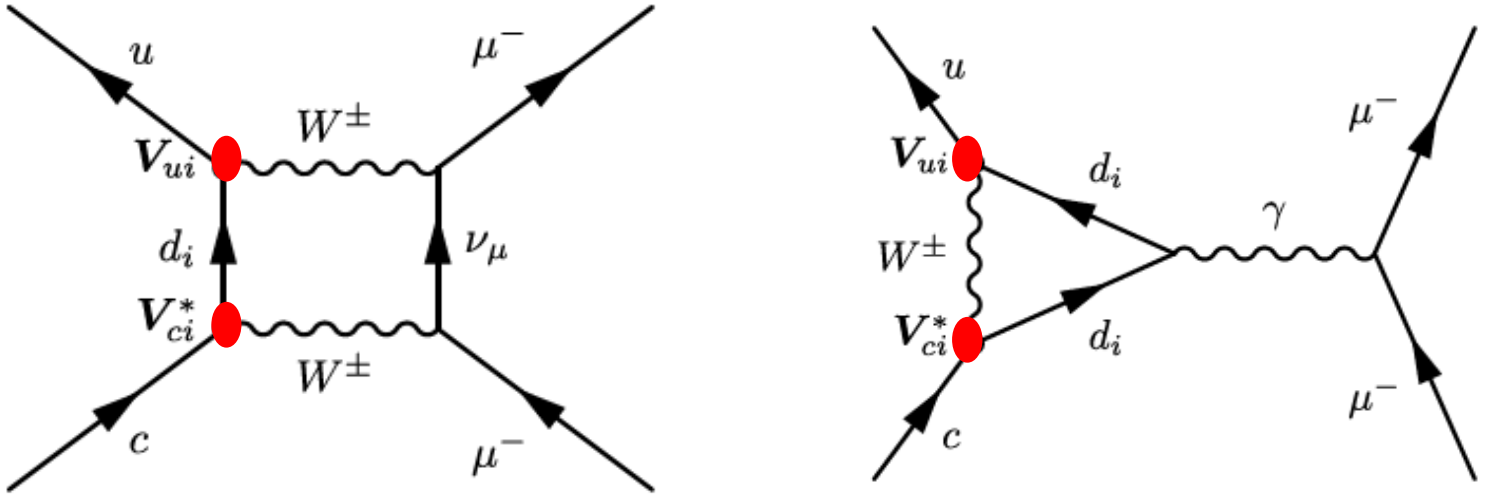
Decay mode	Significance of Signal	Upper Limit (10^{-6})
$B \to K e^{\pm}\mu^{\mp}$	0.0σ	1.6
$K^* e^{\pm}\mu^{\mp}$	2.0σ	6.2
$\pi e^{\pm}\mu^{\mp}$	0.0σ	1.6
$\rho e^{\pm}\mu^{\mp}$	0.6σ	3.2
$B^+ \to K^- e^+ e^+$	0.0σ	1.0
$K^{*-} e^+ e^+$	0.0σ	2.8
$\pi^- e^+ e^+$	0.0σ	1.6
$\rho^- e^+ e^+$	1.1σ	2.6
$B^+ \to K^- e^+ \mu^+$	0.0σ	2.0
$K^{*-} e^+ \mu^+$	0.0σ	4.4
$\pi^- e^+ \mu^+$	0.0σ	1.3
$\rho^- e^+ \mu^+$	0.3σ	3.3
$B^+ \to K^- \mu^+ \mu^+$	0.0σ	1.8
$K^{*-} \mu^+ \mu^+$	0.5σ	8.3
$\pi^- \mu^+ \mu^+$	0.0σ	1.4
$\rho^- \mu^+ \mu^+$	1.0σ	5.0

5.1×10^{-7} → PRD 73, 092001 (2006)

3.8×10^{-8}

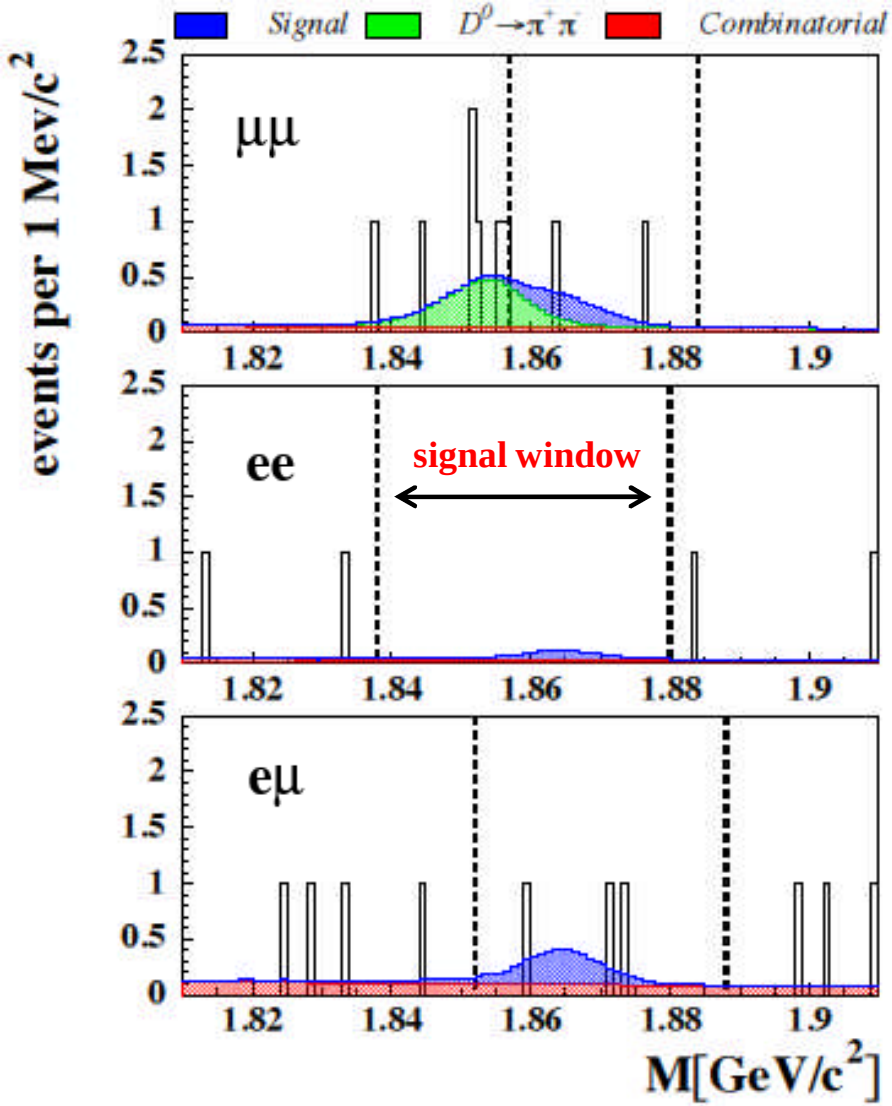
9.2×10^{-8} → PRL 99, 051801 (2007)

Search for leptonic D^0 decays



- The FCNC decays $D^0 \to \ell^+\ell^-$ (ℓ = e or μ) are highly suppressed in the SM because of the GIM mechanism **PRD 2, 1285 (1970)**
- Potential NP scenarios, such as *R*-parity violating SUSY, can raise the BFs close to current expt. sensitivity **PRD 79, 114030 (2009)**
- The LFV decay $D^0 \to \ell^+\ell'^-$ is SM forbidden, but is possible in extensions of the SM (nondegenerate neutrinos etc.) **PRD 66, 014009 (2002)**
  - below current sensitivity ➡ any signal is a signature of NP

Recent Results from Belle



PRD 81, 091102(R) (2010)

- No evidence for signal

	$D^0 \to \mu^+\mu^-$	$D^0 \to e^+e^-$	$D^0 \to e^\pm\mu^\mp$
N_{bkg}	3.1 ± 0.1	1.7 ± 0.2	2.6 ± 0.2
N	2	0	3
$\epsilon_{\ell\ell}[\%]$	7.02 ± 0.34	5.27 ± 0.32	6.24 ± 0.27
$\epsilon_{\pi\pi}[\%]$	12.42 ± 0.10	10.74 ± 0.09	11.22 ± 0.09
$f[10^{-8}]$	$4.84(1 \pm 5.3\%)$	$6.47(1 \pm 6.4\%)$	$5.48(1 \pm 4.8\%)$
UL $[10^{-7}]$	1.4	0.79	2.6

- Competitive 90% UL from CDF

$\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.1 \times 10^{-7}$ arXiv:1008.5077

- Constraint on RPV couplings
- Strongly disfavors a leptoquark contribution as the explanation for the observed f(D_S) anomaly

PLB 682, 67 (2009) predicted $\mathcal{B}_{\mu\mu} \sim 8 \times 10^{-7}$

Extending the search to $B_{(s)}$ decays

- B factories and Tevatron are intensively searching for leptonic B^0 decays

Expt	$B^0 \to$	90% UL on BF	Reference
CDF	e^+e^-	8.3×10^{-8}	PRL 102, 201801 (2009)
CDF	$\mu^+\mu^-$	7.6×10^{-9}	CDF public note 9892
BaBar	$\tau^+\tau^-$	4.1×10^{-3}	PRL 96, 241802 (2006)
CDF	$e^+\mu^-$	6.4×10^{-8}	PRL 102, 201801 (2009)
BaBar	$e^+\tau^-$	2.8×10^{-5}	PRD 77, 091104(R) (2008)
BaBar	$\mu^+\tau^-$	2.2×10^{-5}	PRD 77, 091104(R) (2008)

- Tevatron has also extended the search to B_s (see talk by I. Bertram this afternoon)
  - current best limits (at 95% CL) from CDF with 3.7 fb^{-1} data

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 4.3 \times 10^{-8}$$

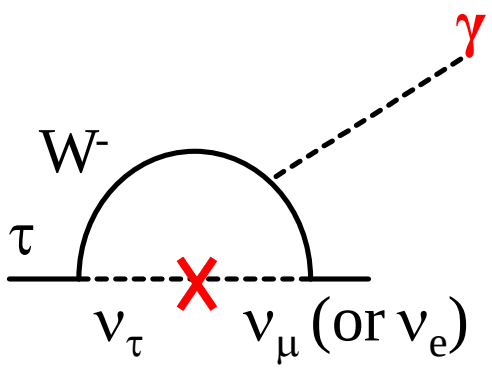
CDF public note 9892

  - neck-to-neck number from D0 using 6.1 fb^{-1} data

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8}$$

arXiv:1006.3469

Lepton flavor violation in τ decays

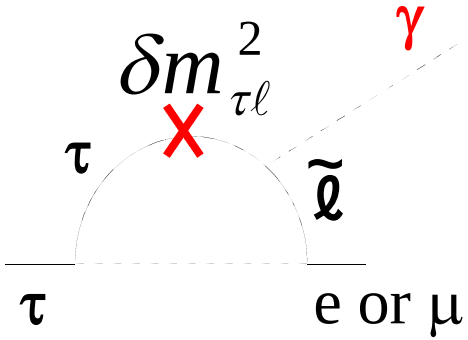


- LFV in τ decays is forbidden in the SM
- Even after including neutrino oscillation, the probability remains negligibly small

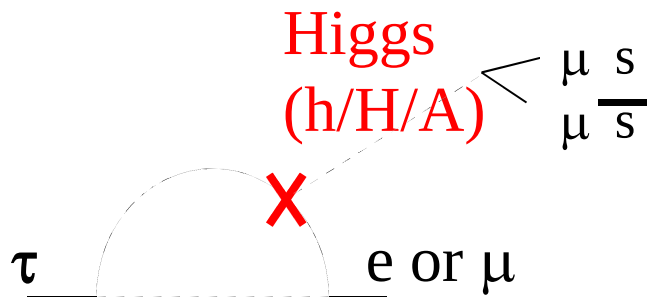
$$\mathcal{B}(\tau \to l\gamma) \propto \left(\frac{\Delta m^2_\nu}{m^2_W}\right)^2 < 10^{-54}$$

EPJ C8, 513 (1999)

- Nonzero signal is therefore a clear signature of NP
- SUSY is the most popular candidate among various NP models; it naturally induces LFV at one-loop level due to the slepton mixing
- To distinguish which model is preferred, we need to search for all possible LFV decays



SUSY-seesaw or SUSY-GUT



Heavier sleptons (mass > m_W)

Analysis Overview

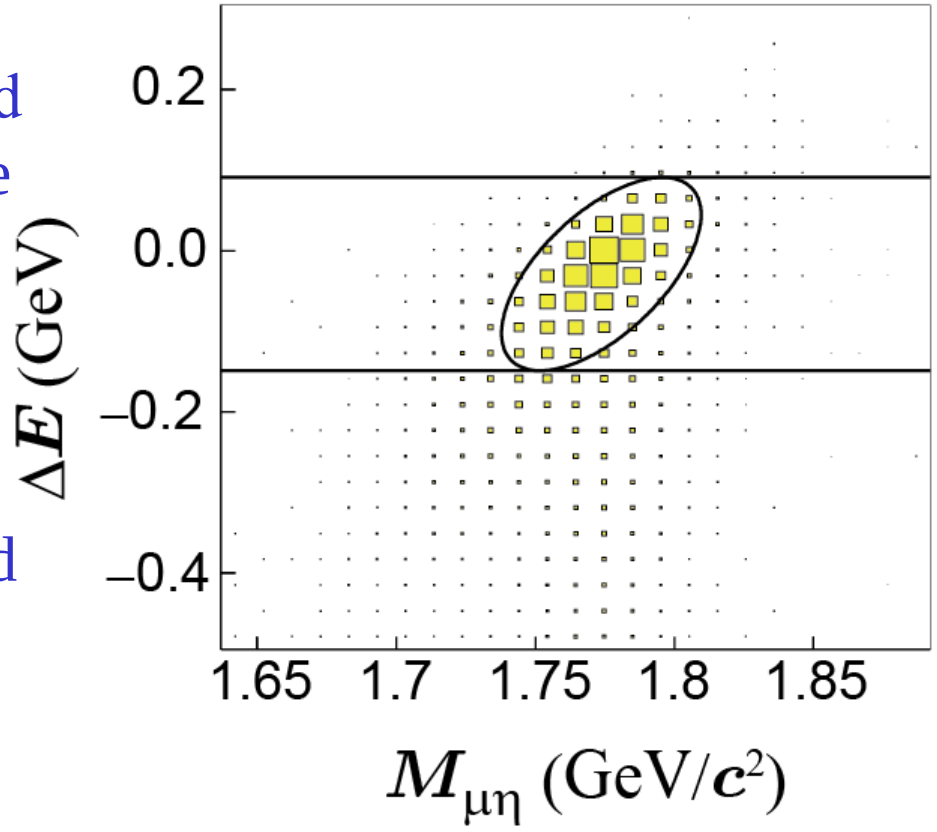
- Start with $e^+e^- \rightarrow \tau^+\tau^-$
  - The τ decaying to 1 prong + missing energy (due to ν) is referred as the 'tag side'
  - Other (signal) τ is assumed to decay to LFV final state

- Blind analysis based on two variables: M_{sig} and ΔE

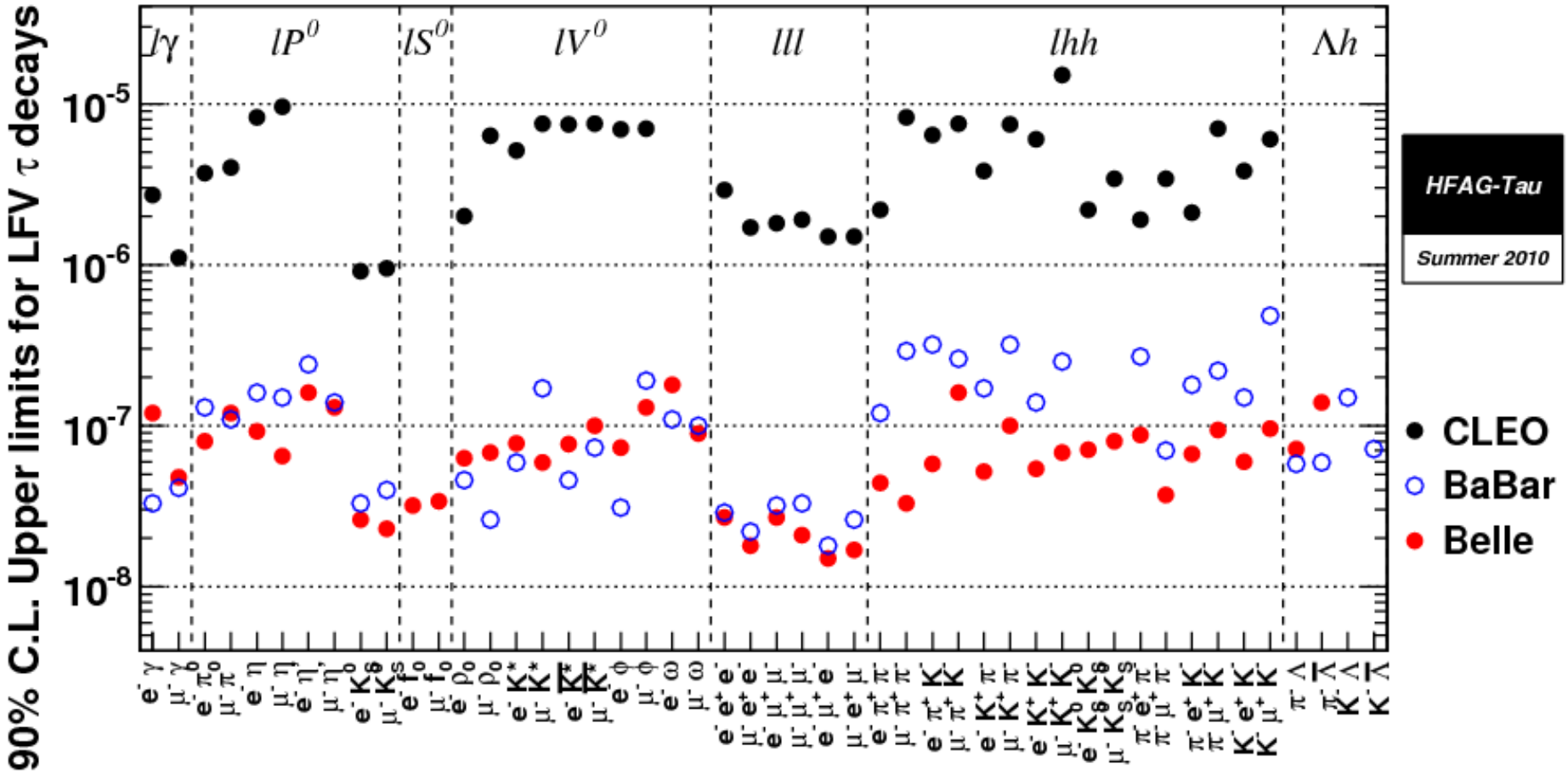
- Estimate expected background in the signal region (shown as an ellipse) using sidebands in data and MC simulations

$$M_{\rm sig} = \sqrt{E_{\rm sig}^2 - \vec{p}_{\rm sig}^{\,2}}$$

$$\Delta E = E_{\rm sig}^{\rm CM} - E_{beam}^{\rm CM}$$

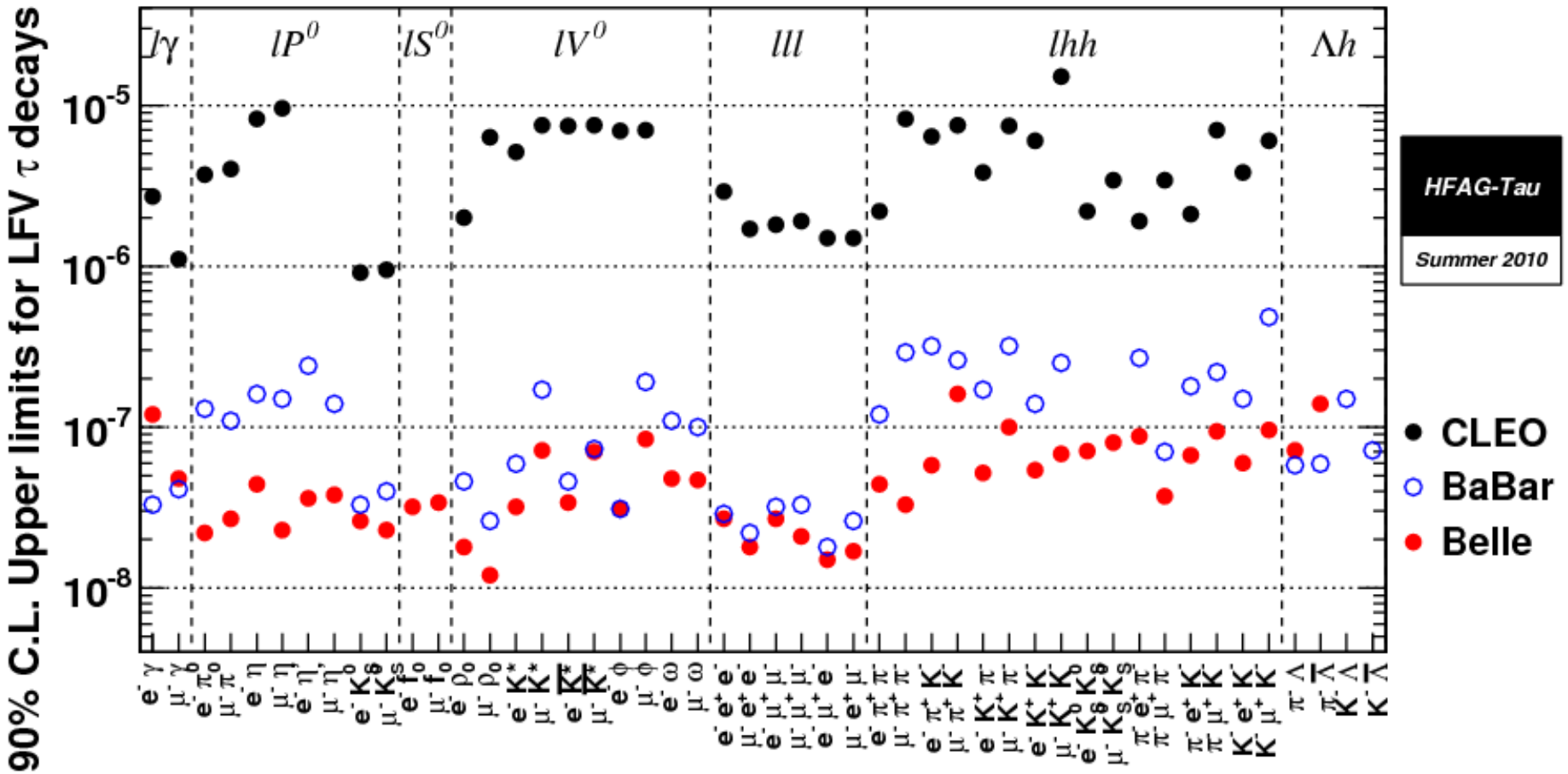


Results before this summer



- Most of the results from  are based on the final dataset

Including latest results from Belle



- The most sensitive result is coming from $\tau^- \rightarrow \mu^-\rho^0$
- Our sensitivity touches the level of 10^{-8}

Closing Remarks

- After accomplishing the major goal of their inceptions (CPV in B decays), the two B-factory experiments have turned their attention to rare decays
- Using a large, clean data sample and sophisticated analysis methodology, we are exploring decays that may not have been thought of at the beginning
- The baton is being slowly handed to the next generation of flavor experiment ➡ LHCb (rare beauty at the LHC)
- With the proposed super flavor factories well in sight, the future seems to be even brighter for experimenters at the intensity frontiers