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PHIPSI 09

Rare tau decays at BABAR

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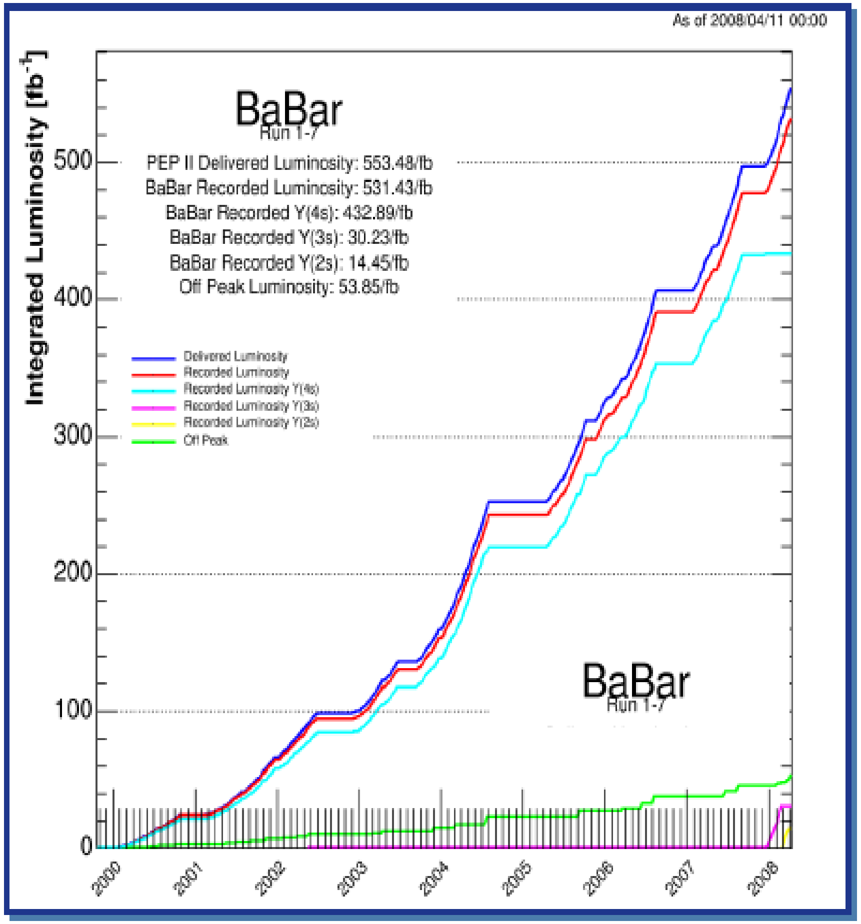
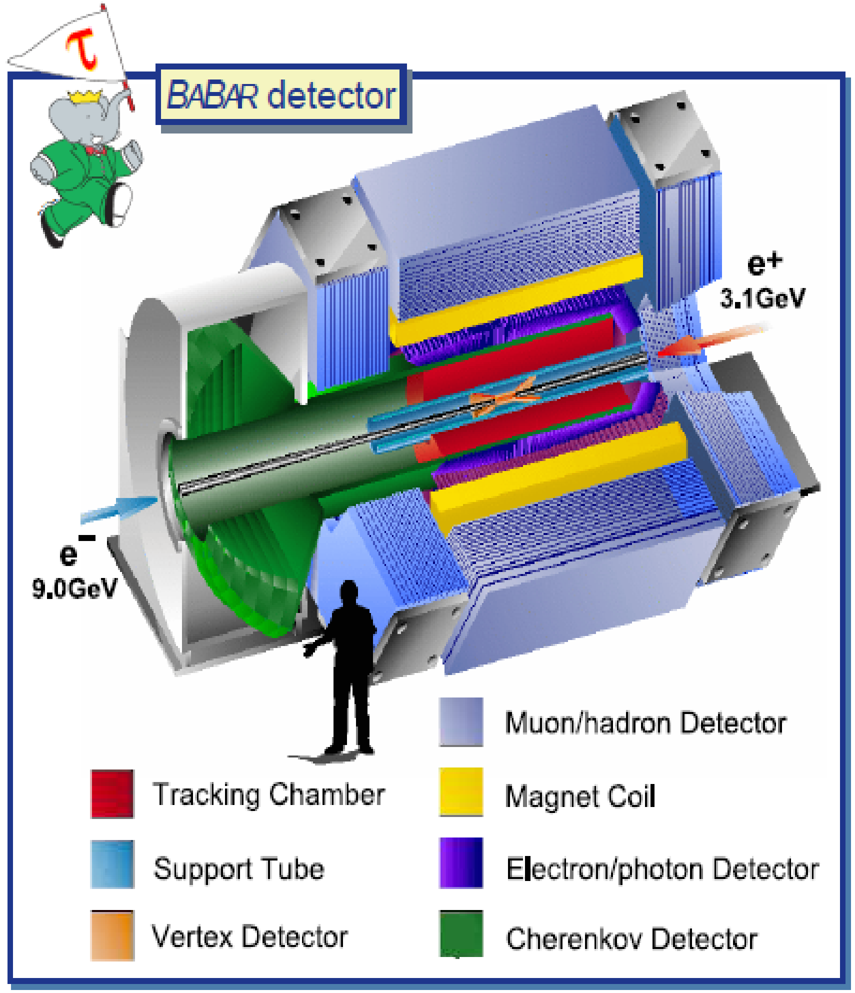
for the BABAR Collaboration

International Workshop on e^+e^- Collisions from Phi to Psi, Beijing, 13 – 16 Oct 2009





BaBar running ended in April 2008 with a total integrated luminosity of 531 fb^{-1}

Tau-pair cross section is 0.9 nb → 488M tau pairs → 976M tau decays

What suppresses rare/forbidden tau decays?

- Standard Model hadronic decays
  - Cabbibo suppresion
  - Helicity suppression
  - Limited phase space
  - J^{PG} : suppression of second-class weak hadronic currents

- Beyond the Standard Model
  - Lepton flavour conservation
  - Baryon number conservation

This talk reports on some examples of the above

Phase-space suppressed tau decays

- Decays to seven (or more) pions
  - If observed, could give information on tau neutrino mass
  - However ... (effective chiral Lagrangian) theory predicts branching fraction of order 10^{-11} (or 10^{-10} if mediated by resonances)

- BABAR limits (at 90% CL):

$BF(\tau^- \to 4\pi^-3\pi^+\nu) < 4.3 \times 10^{-7}$

$BF(\tau^- \to 4\pi^-3\pi^+\pi^0\nu) < 2.5 \times 10^{-7}$

Phys Rev D RC 72,012003(2005)

$BF(\tau^- \to 3\pi^-2\pi^+2\pi^0\nu) < 3.4 \times 10^{-6}$

$BF(\tau^- \to 2\omega\pi^-\nu) < 5.4 \times 10^{-7}$

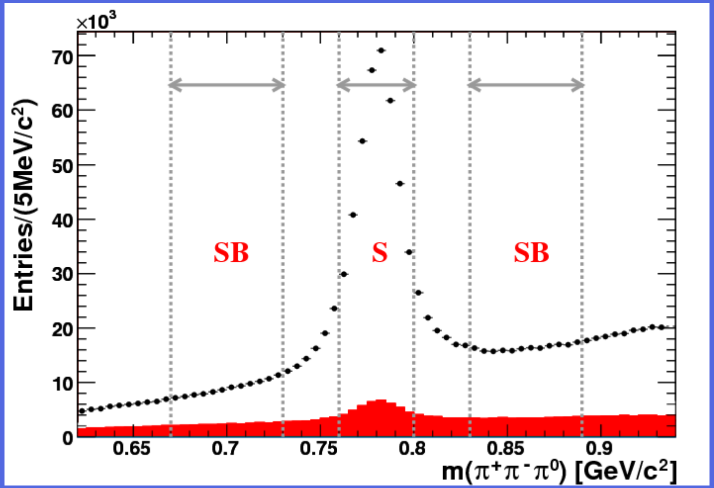
Phys Rev D 73,112003(2006)

Second-class weak hadronic currents

- Weak (V-A) non-strange hadronic currents are classified according to values of spin-parity and G-parity, J^{PG}
- First-class currents dominate hadronic tau decays and have $J^{PG} = 0^{++}$ / 0^{--} (π^-) / 1^{+-} (a_1^-) / 1^{-+} (ρ^-)
- Second-class currents (SCC) have an amplitude proportional to u-d quark mass difference, and have $J^{PG} = 0^{+-}$ ($a_0(980)^-$) / 0^{-+} / 1^{++} ($b_1(1235)^-$) / 1^{--} ($\pi_1(1400)^-$)
- SCC in tau decays expected at a level ~O(10^{-5})
- Difficult to measure because of large backgrounds

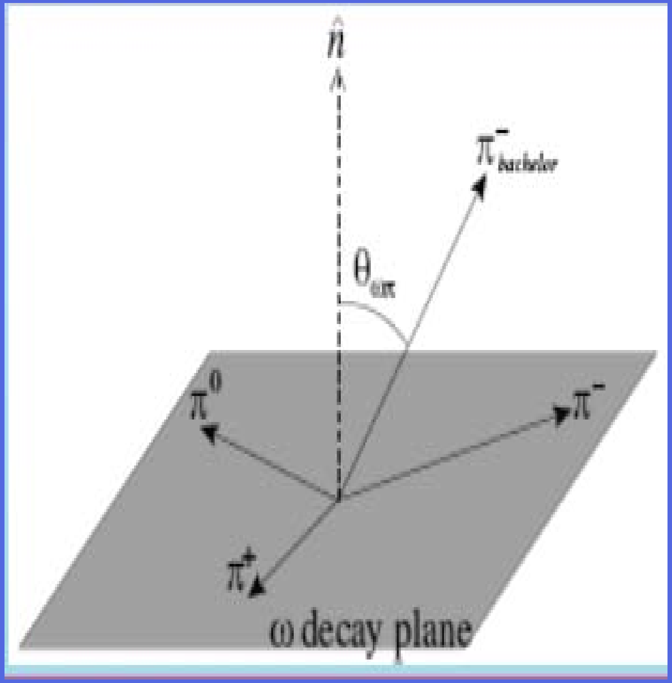
Search for second-class current in $\tau^- \to \omega\pi^-\nu$

Phys Rev Lett 103,041802(2009)



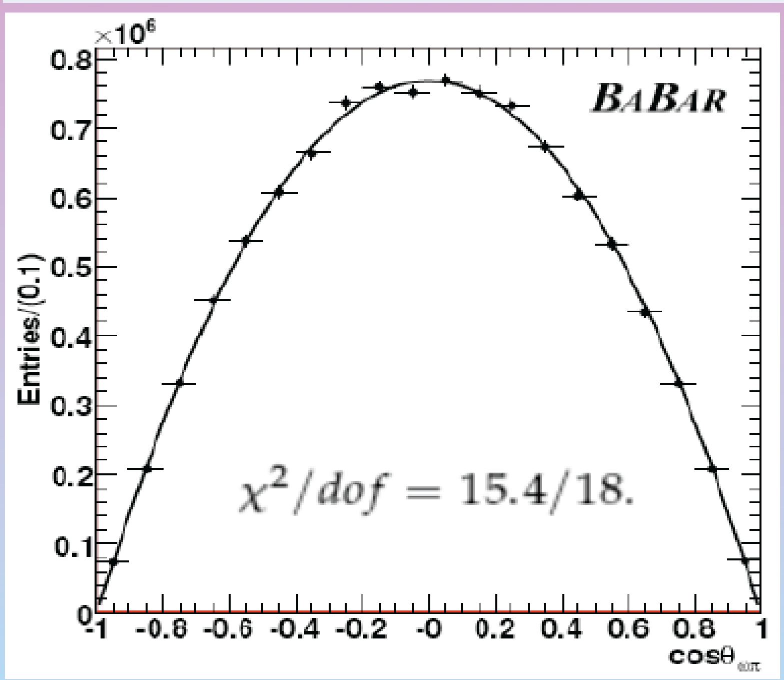
- Analysis using 347 fb-1 of BABAR data
- The $\omega\pi^-$ system has G = +1
- Using decay angular distributions to measure contributions from different J^P states

	J^P	L	$F(\cos\theta_{\omega\pi})$
First class	1^-	1	$(1-\cos^2\theta_{\omega\pi})$
Second class	0^-	1	$\cos^2\theta_{\omega\pi}$
	1^+	0	1
	1^+	2	$(1+3\cos^2\theta_{\omega\pi})$



Search for second-class current in $\tau^- \to \omega\pi^-\nu$

$$F(\cos\theta_{\omega\pi}) = N[(1-\epsilon)F^{FCC}(\cos\theta_{\omega\pi}) + \epsilon F^{SCC}_{L=0}(\cos\theta_{\omega\pi})]$$



where $F^{FCC}(x) \propto (1-x^2)$ and $F^{SCC}_{L=0}(x) \propto (1)$

Phys Rev Lett 103,041802(2009)

$\mathcal{L} = 347$ fb^{-1}

Source	Uncertainty (σ_ϵ)
$\mathcal{B}(\tau^- \to \omega\pi^-\pi^0\nu_\tau)$	± 0.0007
un-simulated τ decays	$^{+0.0000}_{-0.0055}$
$q\bar{q}$ scaling	± 0.0001
Total	$^{+0.0008}_{-0.0055}$

The result from the fit is $\epsilon = (-5.5 \pm 5.8(\text{stat.})^{+0.8}_{-5.5}(\text{syst.})) \times 10^{-3}$.

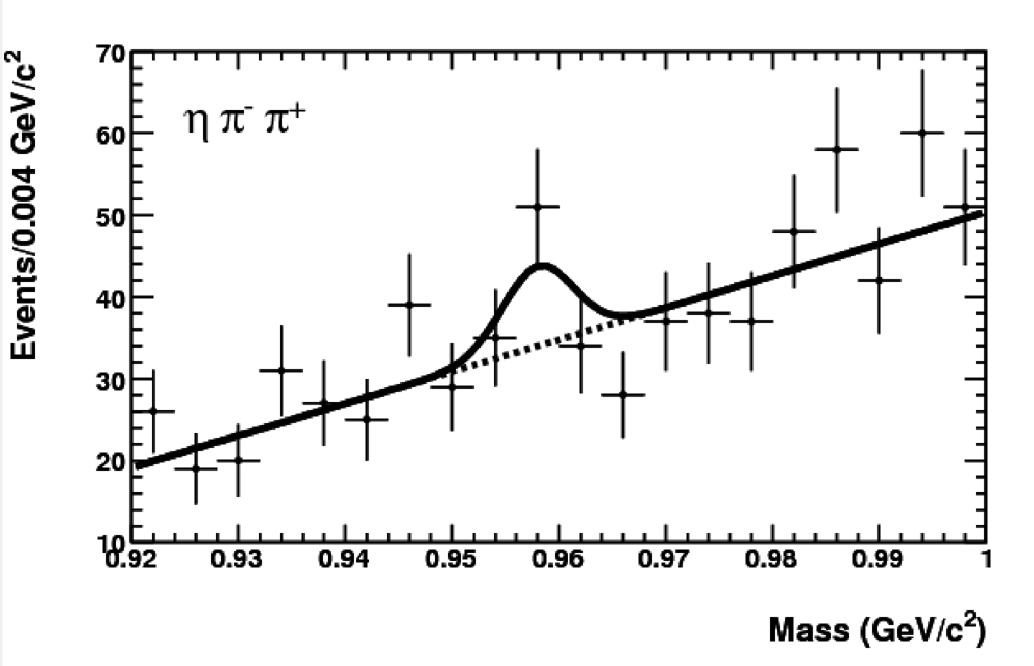
This sets limits in terms of $N^{\omega\pi}_{(\text{non-vector current})}/N^{\omega\pi}_{(\text{vector current})}$ of 0.69% at 90% C.L.

Previous best limit was at 5.4% at 90% C.L. (CLEO)

BF ($\tau^- \to \omega\pi^-\nu$) via SCC < 1.4×10^{-4} at 90% CL

Search for second-class current in $\tau^- \to \eta'\pi^-\nu$

- An $\eta'\pi^-$ system in tau decay has $J^{PG} = 0^{+-}$ or 1^{--}
- So it can only be produced via a second-class current



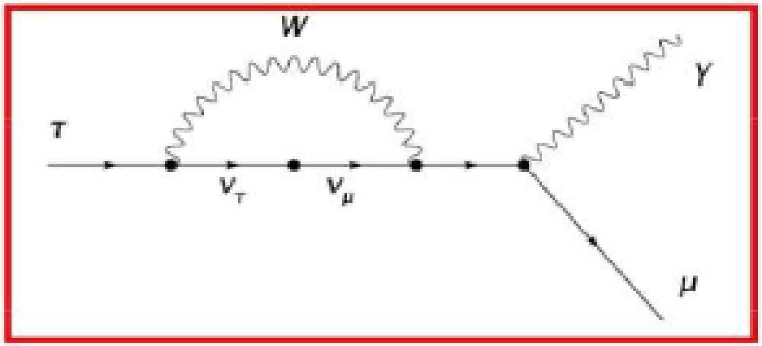
Mass spectrum of $\eta\pi^-\pi^+$ in $\tau^- \to \eta\pi^-\pi^+\pi^-\nu$ candidates

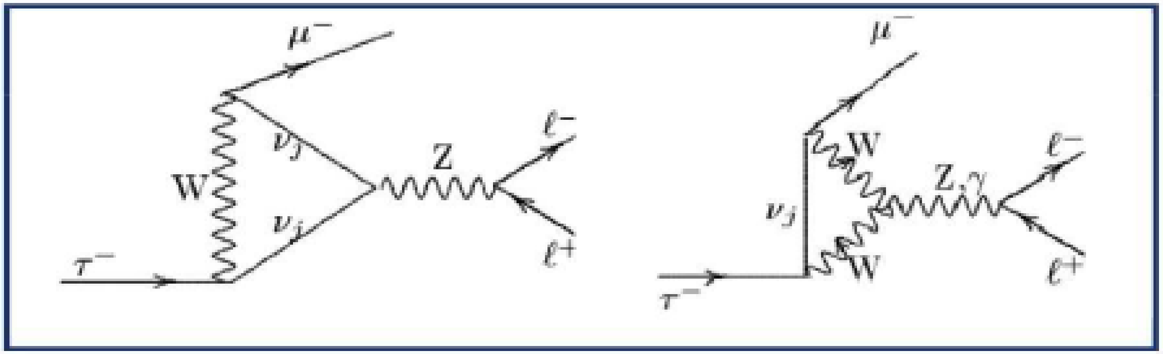
BF($\tau^- \to \eta'\pi^-\nu$) < 7.2 x 10^{-6} at 90% confidence level

Phys Rev D77, 112002(2008)

Searches for Lepton Flavour Violation

- In SM, LFV allowed at rates too low to be detectable, since neutrino mass differences are very small



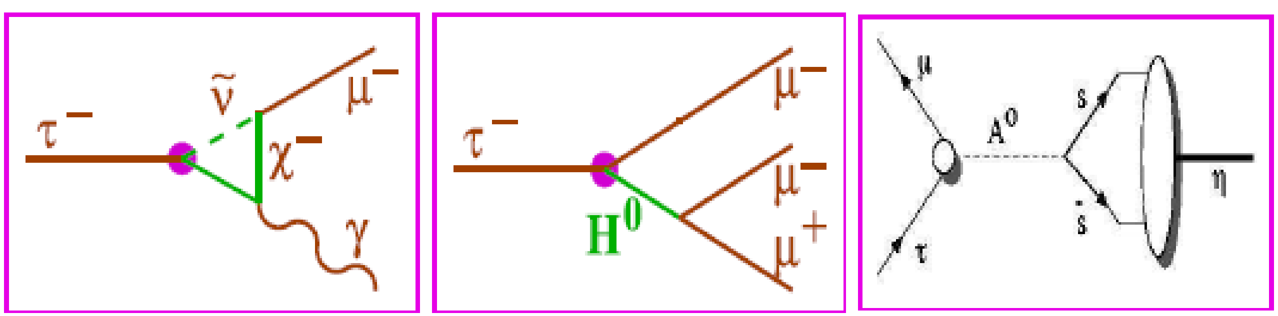


- LFV decays of τ or μ have a clean experimental signature: the lepton is fully reconstructed, no undetected neutrinos
- Then, any experimental observation of LFV is a clear evidence of NP
- Many models beyond SM allow for some LFV rates within experimental reach (10^{-7}-10^{-8})

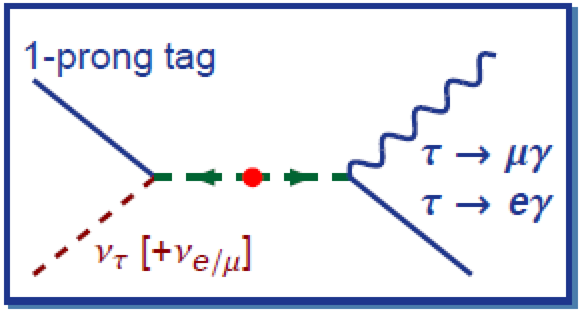
SM and New Physics predictions for LFV in tau decay

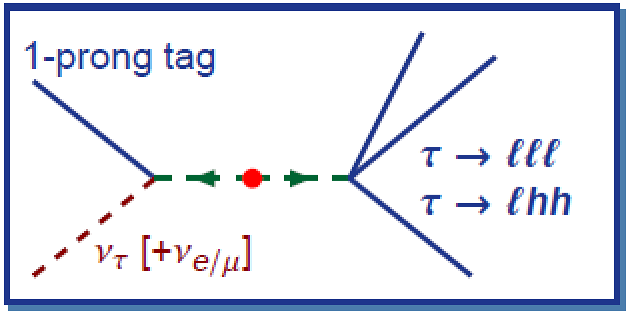
Model	Publication	$\tau \to \ell\gamma$	$\tau \to \ell\ell\ell$
SM + ν mixing	PRD 16 (1977) 1444 PRD 45 (1980) 1908	Undetectably small	
SUSY Higgs	PLB 549 (2002) 159 PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY $SO(10)$	NPB 649 (2003) 189 PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	EPJ C14 (2002) 319 PRD 66 (2002) 115013	10^{-7}	10^{-9}
SM + heavy Dirac ν	PRD 62 (2000) 036010 NP B437 (1995) 491	10^{-6}	–

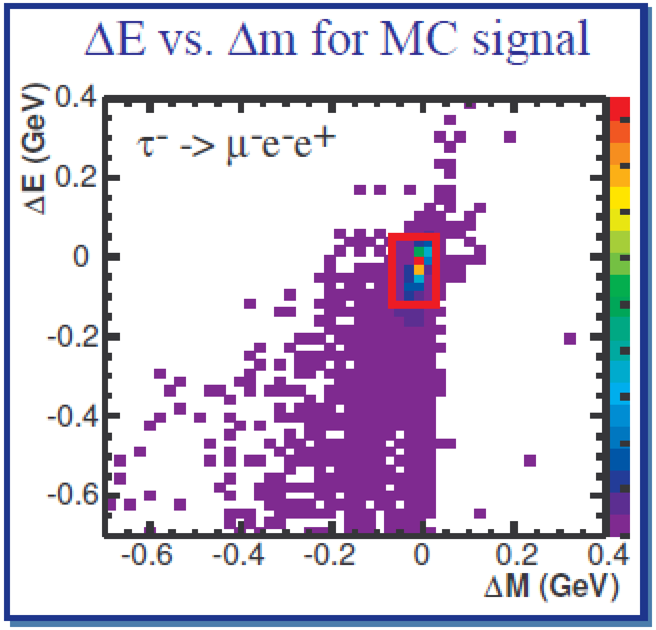
Some possible LFV diagrams involving new physics



Basic event selections and analysis techniques for LFV







- $\tau^+\tau^-$ decay hemishperes separated at $\Upsilon(4S)$
- in tau LFV decay hemishpere
  - neutrinoless tau decay
  - inv. mass decay products = M_τ
  - sum of energies = E_τ = E_{beam}
- $\Delta M = M_{reco} - M_\tau \approx 0$ $\Delta E = E_{reco} - E_{beam} \approx 0$

- **tag hemisphere** ordinary tau decay
  - 1- or 3-prongs, $E < E_{beam}$, $M < M_\tau$
- plot events in ΔE vs. ΔM graph
- count events in signal box, or max LH fit
- expected background from data side-bands

Selection strategy:

Three regions defined in (ΔM, ΔE) plane

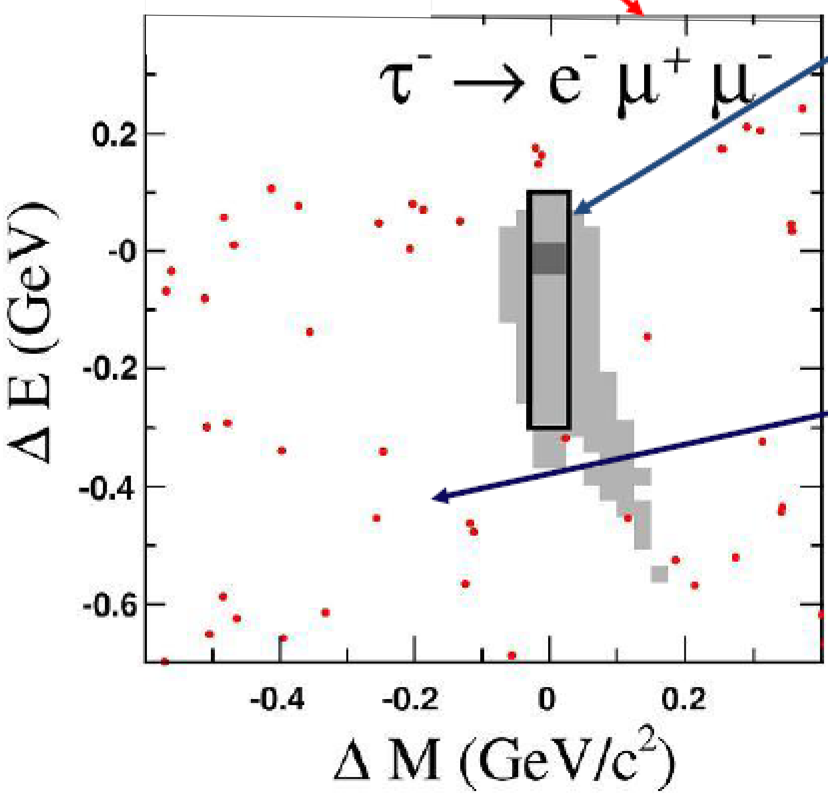
Large Box (LB): identical for all channels. Almost all signal events lie in this region

Signal Box (SB): different for each channel, dimension optimized to give the best UL for each channel.

Data events in this region are BLIND

Grand Sideband (GS): is the unblinded region of the LB.

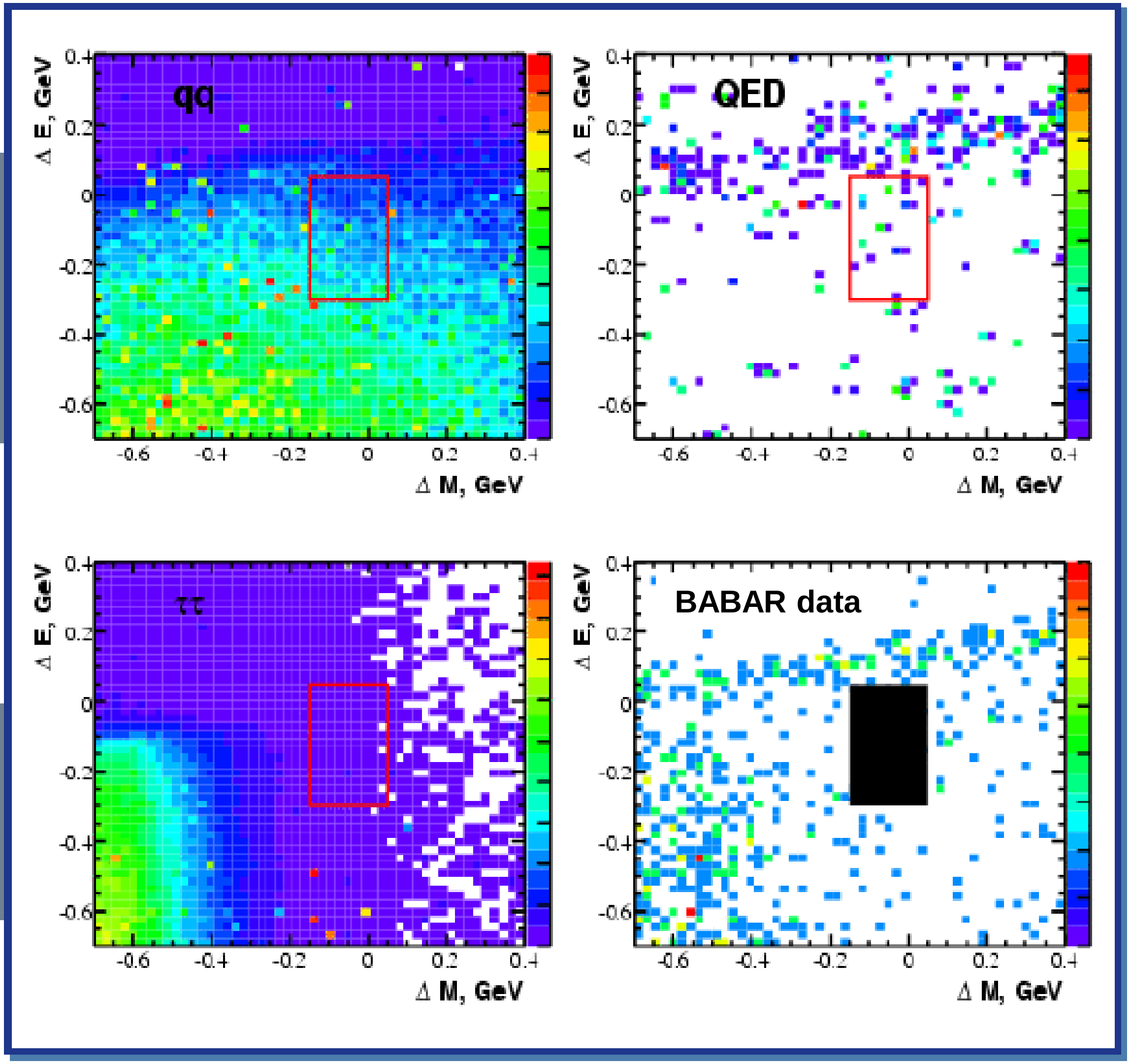
Background estimation made extrapolating data from GS to SB



Typical backgrounds in searches for LFV tau decays

$q\bar{q}$ (uds, $c\bar{c}$, $b\bar{b}$)
($b\bar{b}$ is negligible)
uniform ΔM
$\Delta E < 0$

$\tau^+\tau^-$, two-photon
$\Delta M < 0$
$\Delta E < 0$



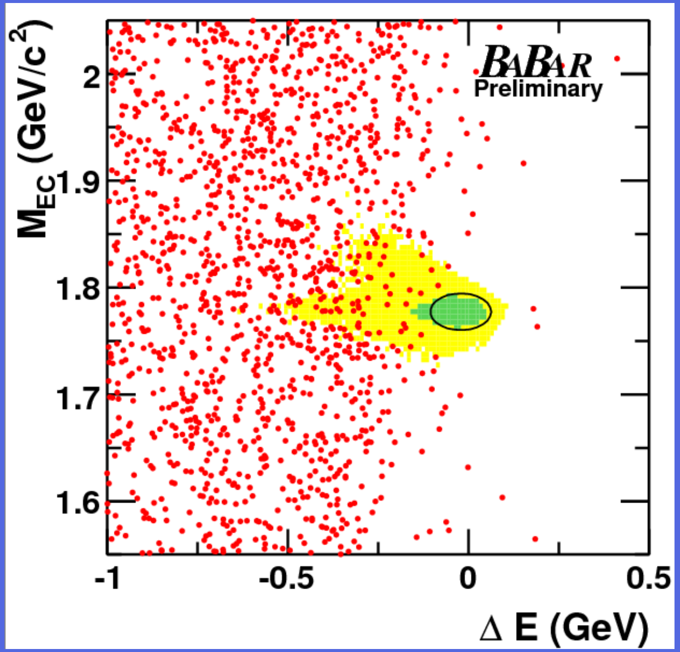
Bhabha, di-muon
uniform ΔM
$\Delta E \approx 0$ band

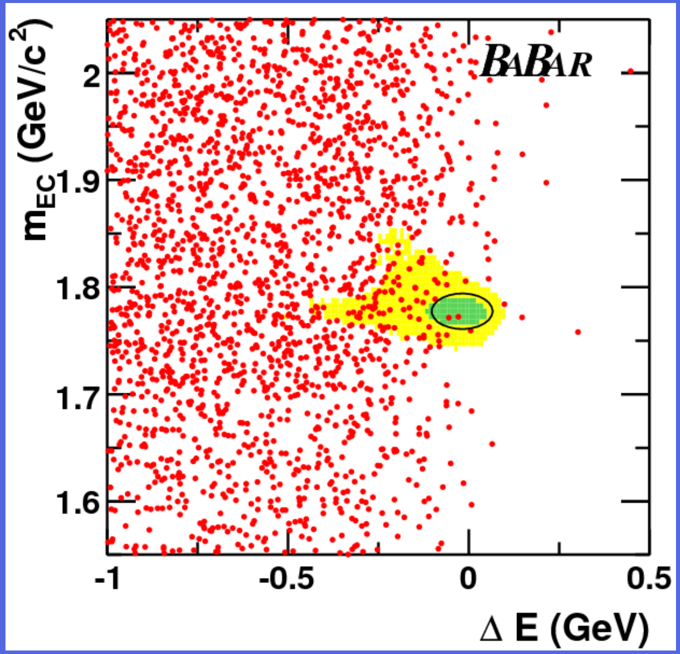
$\tau \to 3\ell$
data candidates

$\tau \to \ell\gamma$

- ΔE, std M_{EC}
- Lumi: **482M τpairs**
- hep-ex 0908.2381
- Improvement from last Belle results
- Submitted to PRL

Mode	$\epsilon(\%)$	$\sigma_{syst}(\%)$	N_{bkg}	N_{obs}	$UL_{90}^{obs}(10^{-8})$
$e\gamma$	3.9	7.7	1.6 ± 0.4	0	3.3
$\mu\gamma$	6.1	7.4	3.6 ± 0.7	2	4.4

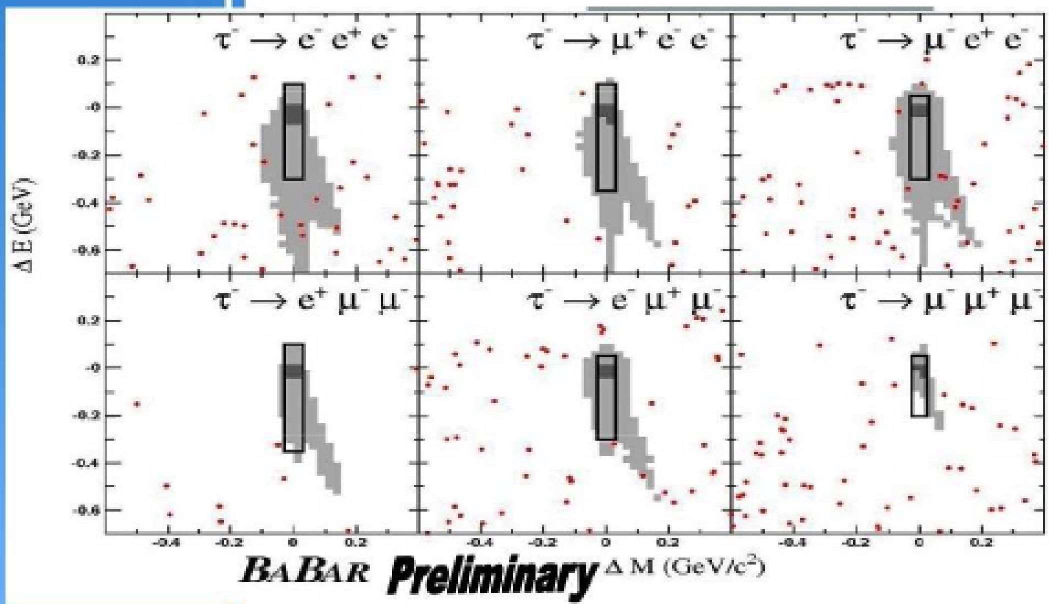




$\tau \rightarrow \ell\ell\ell$

- Lumi: **430M τ pairs**
- No signal observed
- Preliminary, to be published on PRD-RC

Mode	$\epsilon(\%)$	$\sigma_{syst}(\%)$	N_{bkg}	N_{obs}	$UL_{90}^{obs}(10^{-8})$
$e^-e^+e^-$	8.6	2.3	0.12 ± 0.02	0	2.9
$e^-e^+\mu^-$	8.8	5.7	0.64 ± 0.19	0	2.2
$e^-\mu^+e^-$	12.6	5.5	0.34 ± 0.12	0	1.8
$e^-\mu^+\mu^-$	6.4	6.2	0.54 ± 0.14	0	3.2
$\mu^-e^+\mu^-$	10.2	5.9	0.03 ± 0.02	0	2.6
$\mu^+\mu^-\mu^+$	6.6	9.0	0.44 ± 0.17	0	3.3

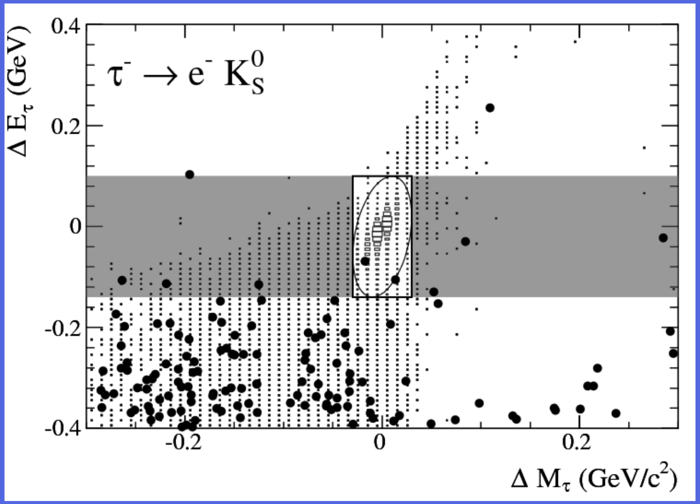


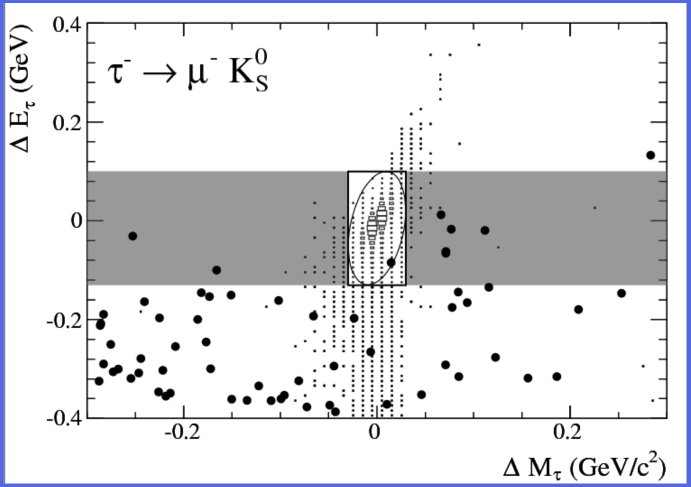
- Major improvements
  - Better event selection with neural network
  - Better PID efficiency, specially for muons (with smaller syst.)
  - UL improved by a factor 2-3 with lumi increased of 25%

Search for $\tau^- \to \ell^- K^0_s$

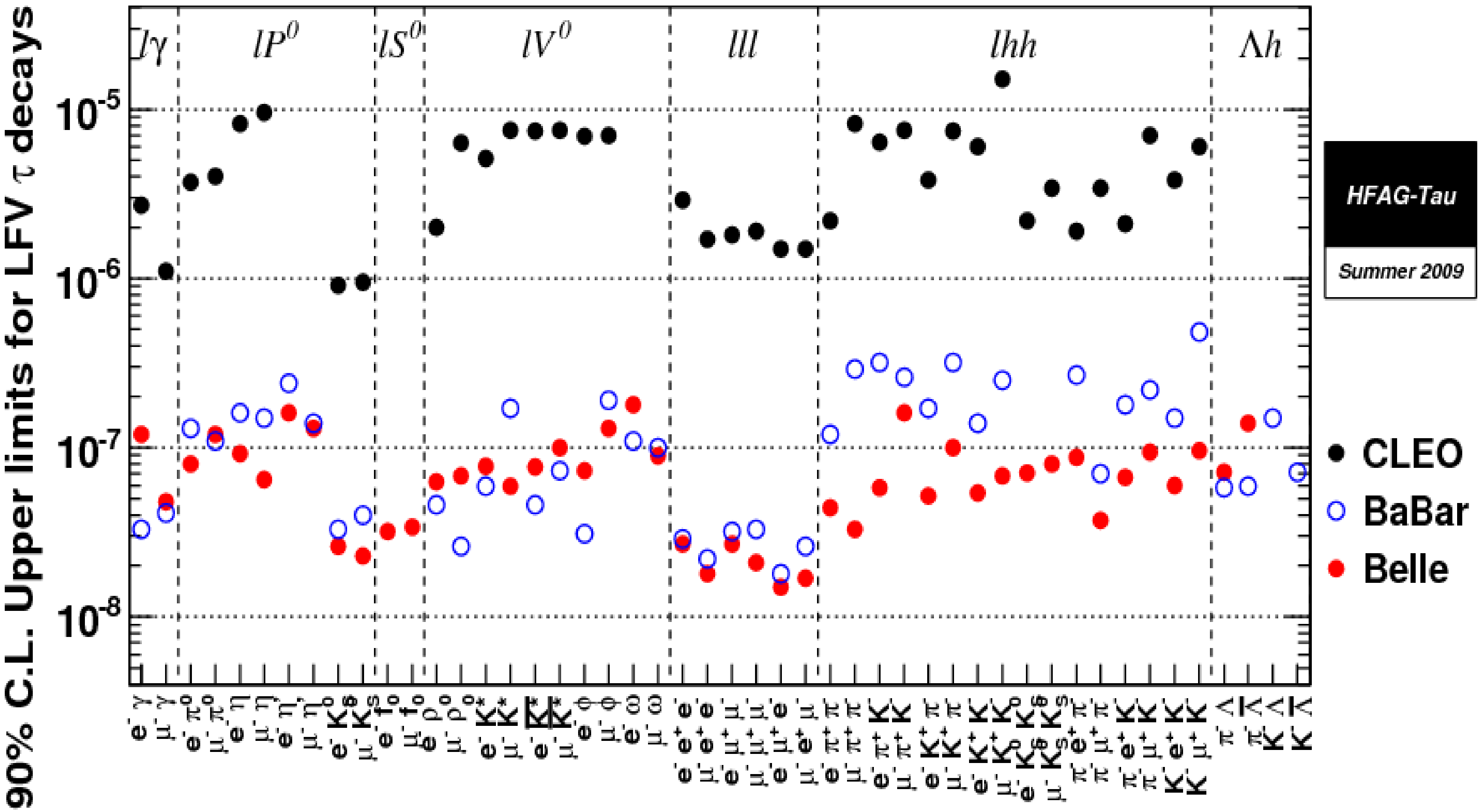
- Analysis using 431M tau pairs
- BF($\tau^- \to e^- K^0_s$) < 3.3 x 10^{-8} at 90% CL
- BF($\tau^- \to \mu^- K^0_s$) < 4.0 x 10^{-8} at 90% CL

Phys Rev D 79,012004(2009)

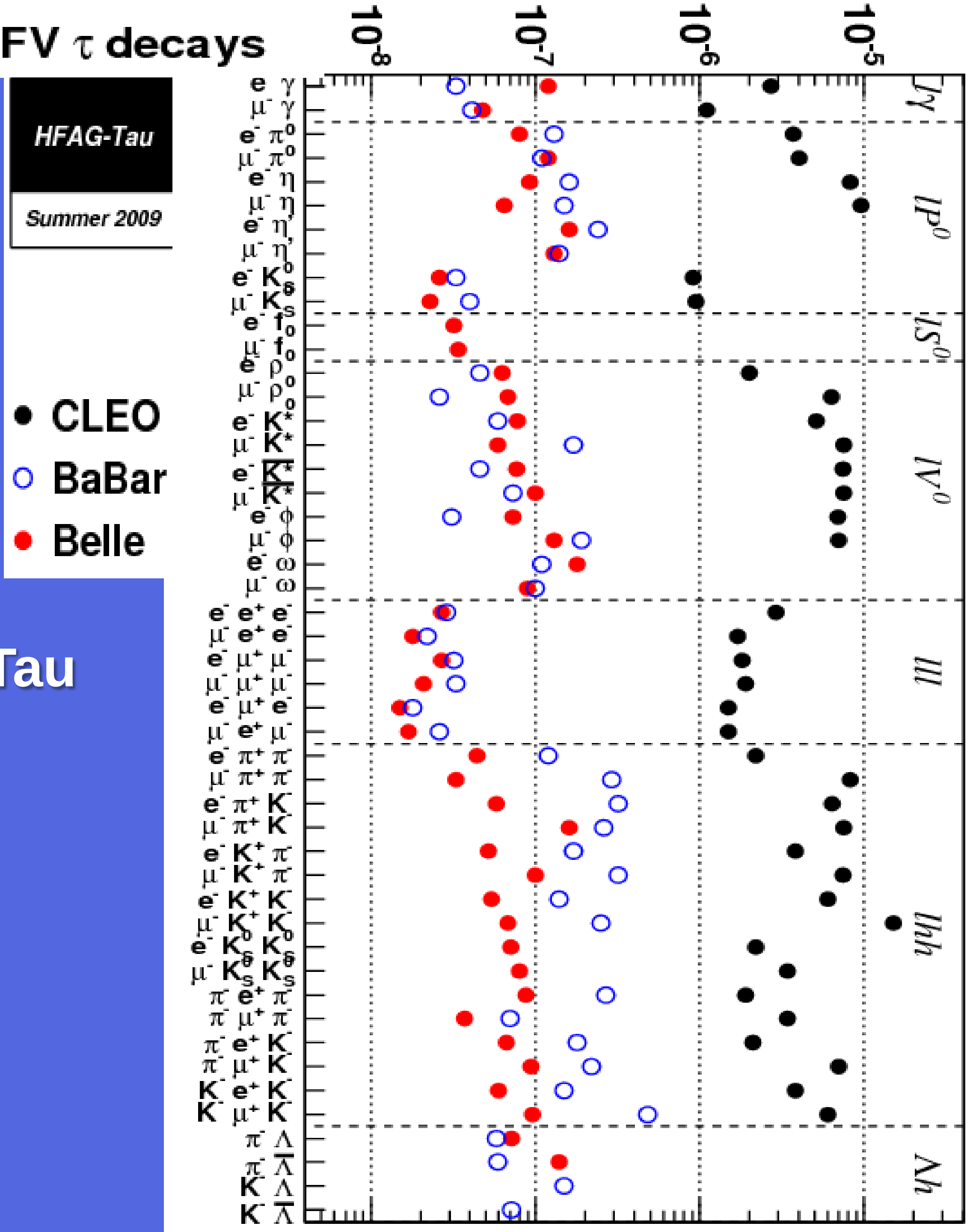




Status of tau LFV results from HFAG-Tau



90% C.L. Upper limits for LFV τ decays



Status of tau LFV results from HFAG-Tau

Conclusions

- BABAR completed data-taking in April 2008
- Final sample comprises almost 10^9 tau decays
- Analyses of rare decay channels now nearing completion
- Some unique results in searches for second-class currents and for high-multiplicity hadronic tau decays
- Many results in searches for Lepton Flavour Violation currently remain competitive with Belle
- HFAG now includes tau results, combining BABAR and Belle
- Thanks to all BABAR colleagues (and particularly to Swagato Banerjee and Alberto Lusiani)