Rare τ decays

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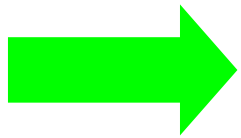
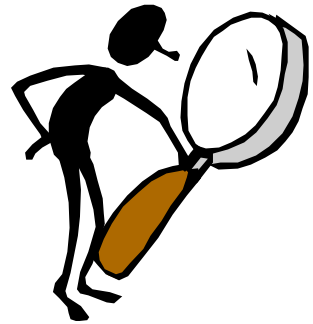
Rare τ decays

SM forbidden (or effectively so…)



Search program for **physics BSM**



Lepton Flavor Violation

To set the stage, take as benchmark the smallest measured Branching Ratio for τ:

$$BR(\tau^- \to \phi K^- \nu_\tau) = \begin{cases} (4.05 \pm 0.25 \pm 0.26)\, 10^{-5} \\ (3.48 \pm 0.20 \pm 0.26)\, 10^{-5} \end{cases}$$

PLB 643 (2006) 5

preliminary, Tau06

SM allowed, Cabibbo suppressed

Outline

- Where to rare τ decays?
- Why eagerly looking for leptonic FCNC?
  - LFV in SM and beyond
- Search for LFV decays: strategy & tools
- Search for LFV decays: Data
  Experimental results
- Impact on BSM scenarios
- Prospects

Where to rare tau decays?

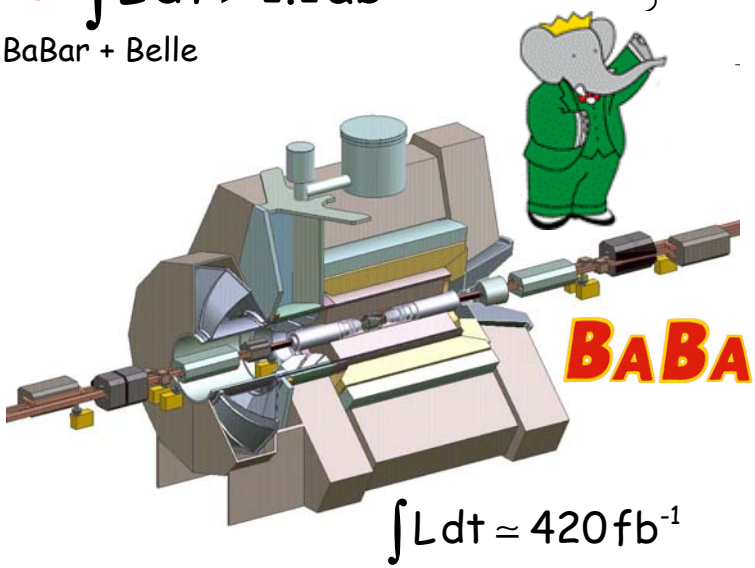
Huge statistics needed for high sensitivity searches

Tau factories!

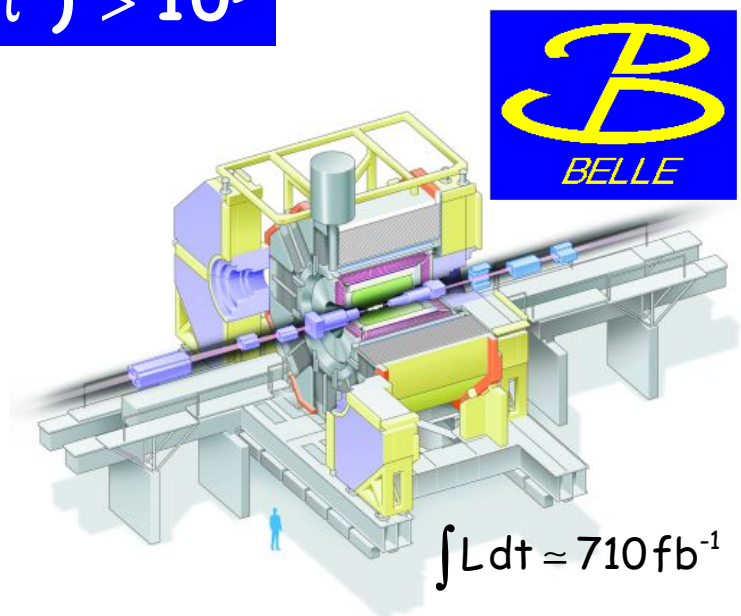
- **Asymmetric B factories** (e^+e^- @ $\sqrt{s}$ = 10.58 GeV)
- $\sigma(e^+e^- \to \tau^+\tau^-) \sim 0.9\,nb$
- $\int L\,dt > 1.1\,ab^{-1}$

BaBar + Belle

$N(\tau^+\tau^-) > 10^9$



$\int L\,dt \simeq 420\,fb^{-1}$



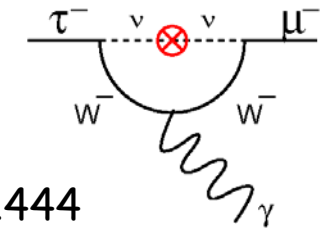
$\int L\,dt \simeq 710\,fb^{-1}$

Lepton Flavor Violation: SM

- SM forbids LFV (no $\nu_R \Rightarrow$ massless neutrinos, LF strictly conserved)
- **LFV observed** in the neutral sector (ν oscillations)
- LFV can be implemented by a "simple" extension of SM (see-saw)
- Tiny ν_L masses $\Rightarrow$ **SM LFV in the charged sector practically unobservable**

$\Delta m^2_{23} \sim 3\,10^{-3}\,\mathrm{eV}^2$ maximal mixing

$$\frac{BR(\tau^- \to \mu^- \gamma)}{BR(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)} = \frac{3\alpha}{128\pi}\left(\frac{\Delta m^2_{23}}{M_W^2}\right)^2 \sin^2 2\theta_{23} \sim 10^{-53}$$

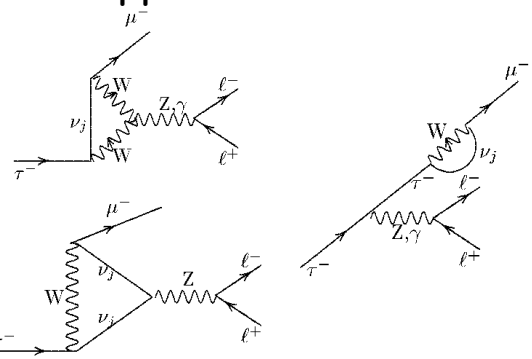


Lee, Shrock
PRD 16 (1977) 1444

Leptonic version of GIM suppression

$$BR(\tau^- \to \mu^- l^+ l^-) = \sum_{k=2}^{3} U_{\tau k} U^*_{\mu k} \ln \frac{m_k^2}{m_1^2} \sim 10^{-14}$$

Pham
EPJ C 8 (1999) 513

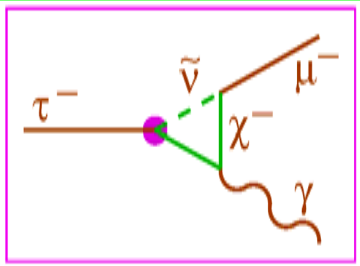


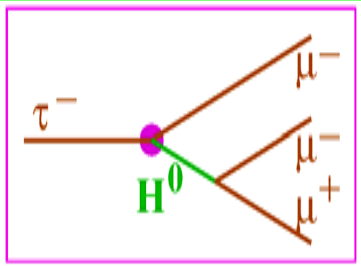
LFV for charged leptons: optimal hunting ground for **non-SM physics effects**

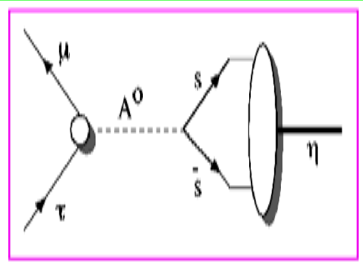
Lepton Flavor Violation: BSM

- Several BSM scenarios allow for LFV BR's not too far or within **experimental reach**
- Different LVF modes (lγ,lll,lhh,…) have different sensitivity to BSM physics

		$\tau \to \mu\gamma$	$\tau \to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908 Pham EPJ C8 (1999) 513	10^{-54} – 10^{-40}	10^{-14}
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

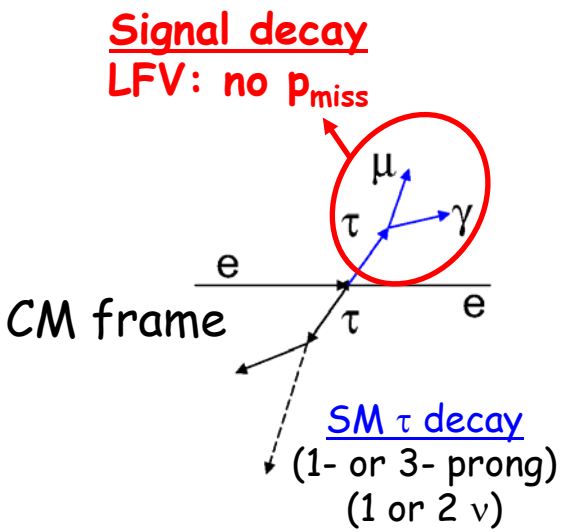


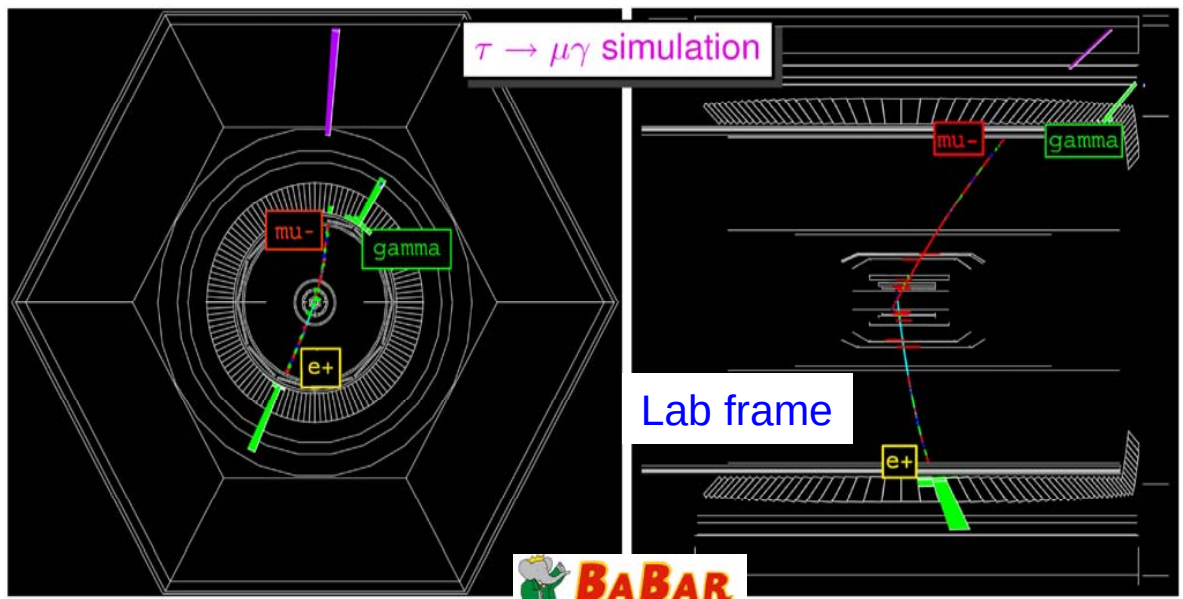




Search for LFV @ e^+e^- colliders

- $e^+e^- \to \tau^+\tau^- \Rightarrow$ **clean environment**
  $\tau^+\tau^-$ back-to-back (CM frame), jet-like
  easy $B\bar{B}$ bkgd rej through event shape variables
- Event easily divided in 2 hemispheres in CM: signal and tag decay
- **Signal (LFV) decay** is neutrinoless: no missing momentum
- Tag (SM) tau decay: 1- or 3- prong (+ 1 or 2 ν)
  (depending on signal and dominant non τ bkgd)





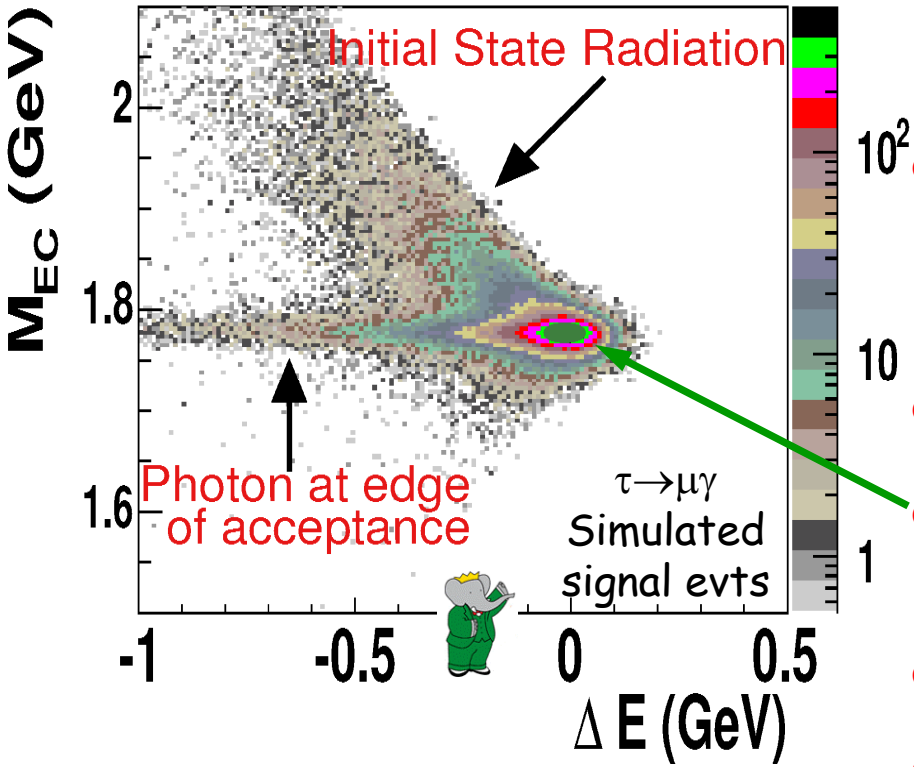
Signal characteristics

- **Lepton Flavor Violating Decay (LFVD): neutrinoless!**

powerful mass and beam energy information:

Smeared by resolution and radiative effects

$$\begin{cases} M_{LFVD} = m_\tau \\ \Delta E \doteq E^{CM}_{LFVD} - \dfrac{\sqrt{s}}{2} = 0 \end{cases}$$



- **Exploiting at best the available constraints** can significantly boost the sensitivity of the search
- e.g. BaBar $\tau \to \mu\gamma$
  - $\sigma(M_{LFVD})$ ~ 20 MeV
  - **$\sigma(M_{LFVD})$ ~ 9 MeV**

Using beam energy constrained mass and γ vtx at μ point of closest appr. to beam axis

- $\sigma(\Delta E)$ ~ 50 MeV
- **Signal region** typically defined as ~ 2 - 3 σ wide around signal
- Cut & count, Likelihood or NN
- Blind analysis

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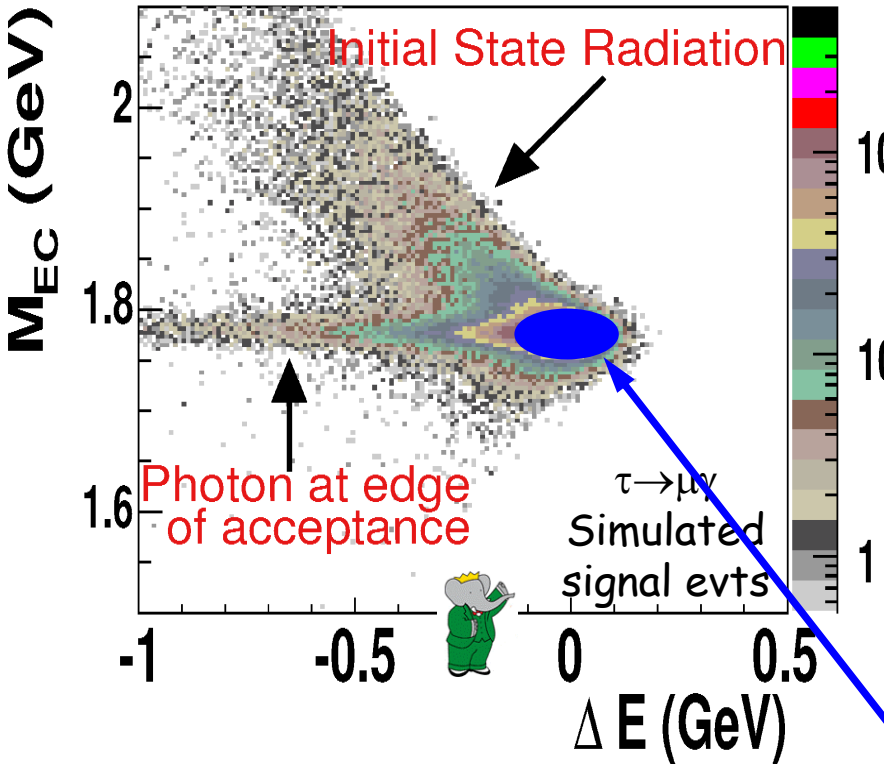

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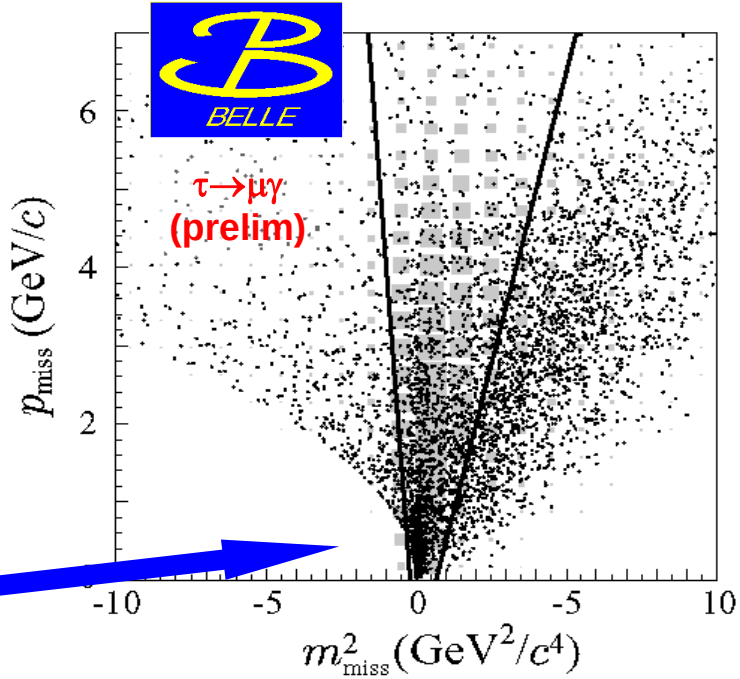
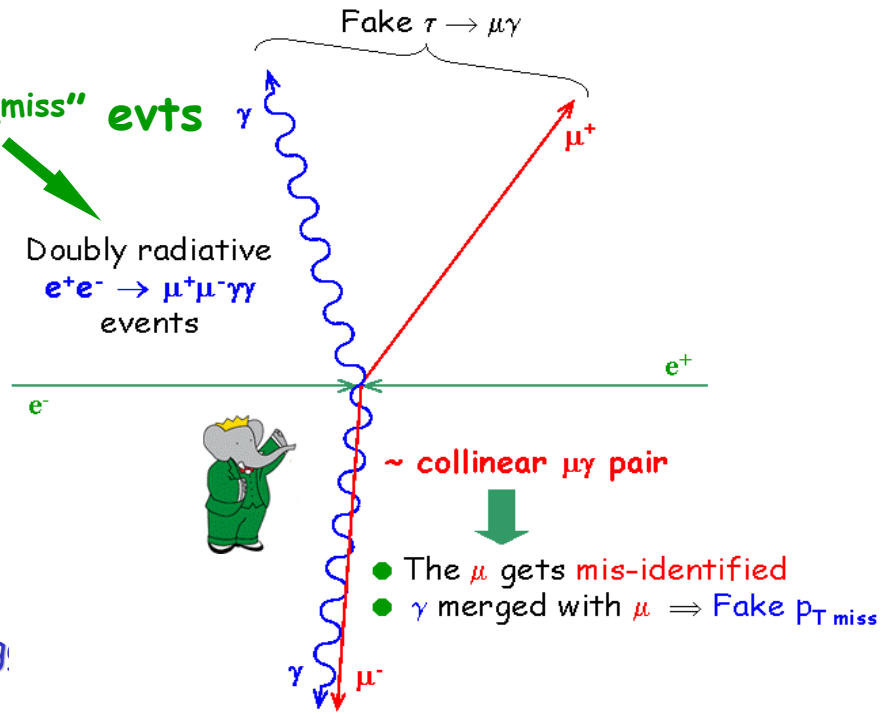
- **Blind analysis**

Other ingredients to LFV searches

- **Powerful PID**
  - $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$
- Exploit (if possible) **other kinematic constraints**
  - $\sqrt{E_{miss}^2 - p_{miss}^2} \sim 0$ for 1ν tag decays
- **Cleverly fight** specific, particularly nasty, bkgs
  - e.g. (BaBar $\tau \to \mu\gamma$), reject **"fake p_T^{miss}" evts**
- Optimize selection strategy/cuts on signal and bkgd **MC samples**
- Model bkgd shapes with MC (checked with data sidebands)
- Bkgd normalization based on **data samples**



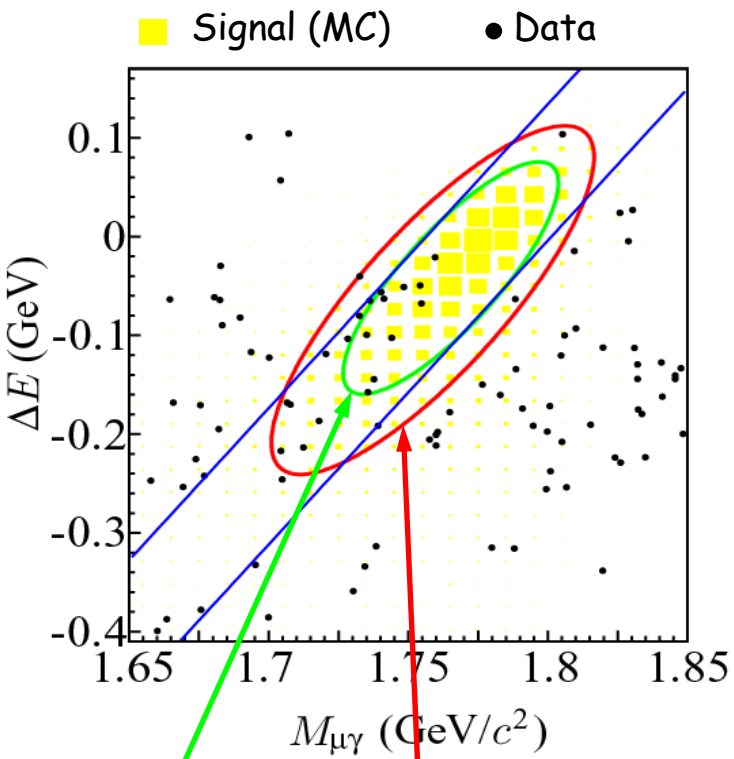


Efficiency for searches typically have the following components:

		cum.
trigger	90%	
acceptance/reconstruction	70%	63%
topology (1vs1, 1 vs 3: hemispheres)	70%	44%
Particle ID	50%	22%
Cuts	50%	11%
Signal-Box	50%	~5%

New (preliminary) Belle result on $\tau \to \mu\gamma$

arXiv:0705.0650[hep-ex]
submitted to PLB



3σ blinded region

2σ signal region: 10 evts
ε = 5.1%

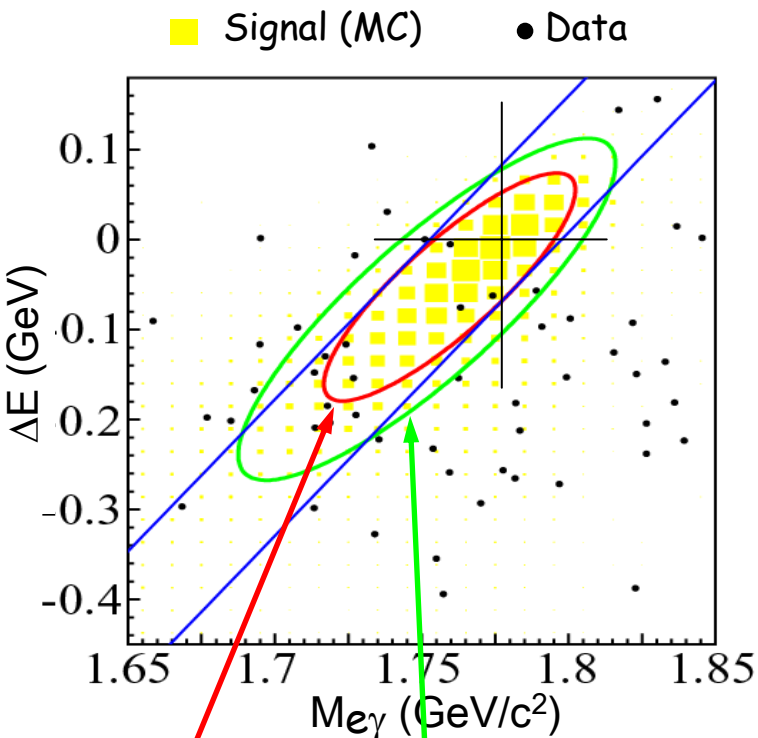
- L = 535 fb^{-1}
- 94 events in 5σ region
- UEML fit in signal region:
  - $s = -3.9^{+3.6}_{-3.2}$
  - $b = 13.9^{+6.0}_{-4.8}$
- Use Toy MC simulation to evaluate the probability of obtaining such result and evaluate the 90% CL
- P($s \leq -3.9$) = 25% for null true signal
- UL on s (90% CL) = 2.0

$$BR(\tau \to \mu\gamma) < 4.5\,10^{-8} \quad (90\%\ CL)$$

Background: ττγ (79%), μμγ (16%), eeγ→eeμμ (5%)

New (preliminary) Belle result on $\tau \to e\gamma$

arXiv:0705.0650[hep-ex]
submitted to PLB



3σ blinded region

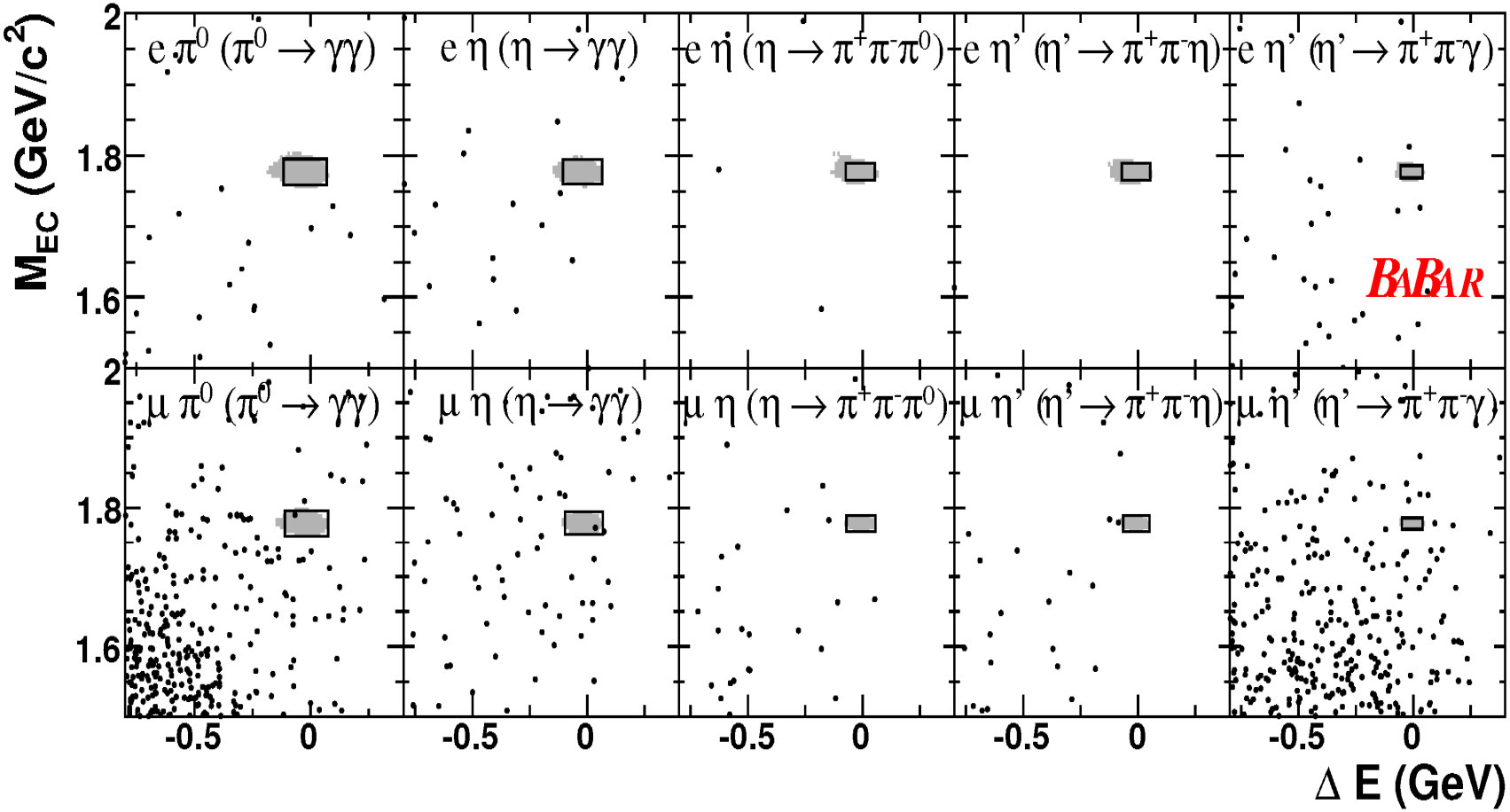
2σ signal region: 5 evts
ε = 3.0%

- **L = 535 fb^{-1}**
- 55 events in 5σ region
- **UEML fit** in signal region:
  - $s = -0.14^{+2.18}_{-2.45}$
  - $b = 5.14^{+3.86}_{-2.81}$
- Use **Toy MC** simulation to evaluate the probability of obtaining such result and evaluate the 90% CL
- P($s \leq -0.14$) = 48% for null true signal
- UL on s (90% CL) = 3.3

$$BR(\tau \to e\gamma) < 1.2\,10^{-7} \quad (90\%\ CL)$$

Background: $\tau\tau\gamma$ (82%), $ee\gamma$ (18%)

Search for $\tau \to l\pi^0$, $l\eta$, $l\eta'$

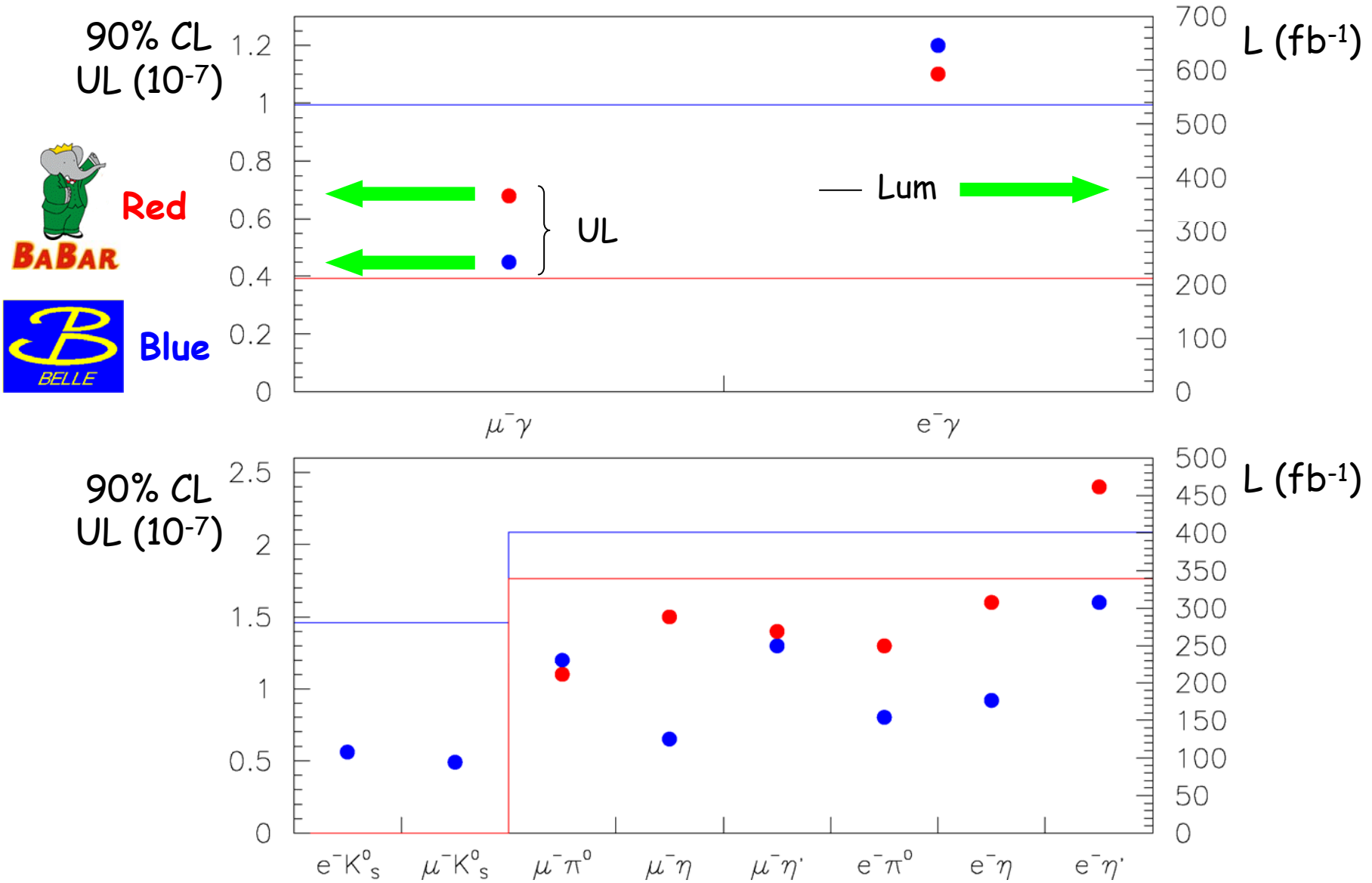


Expected: N_{bkgd}/channel ~ 0.1 – 1.3

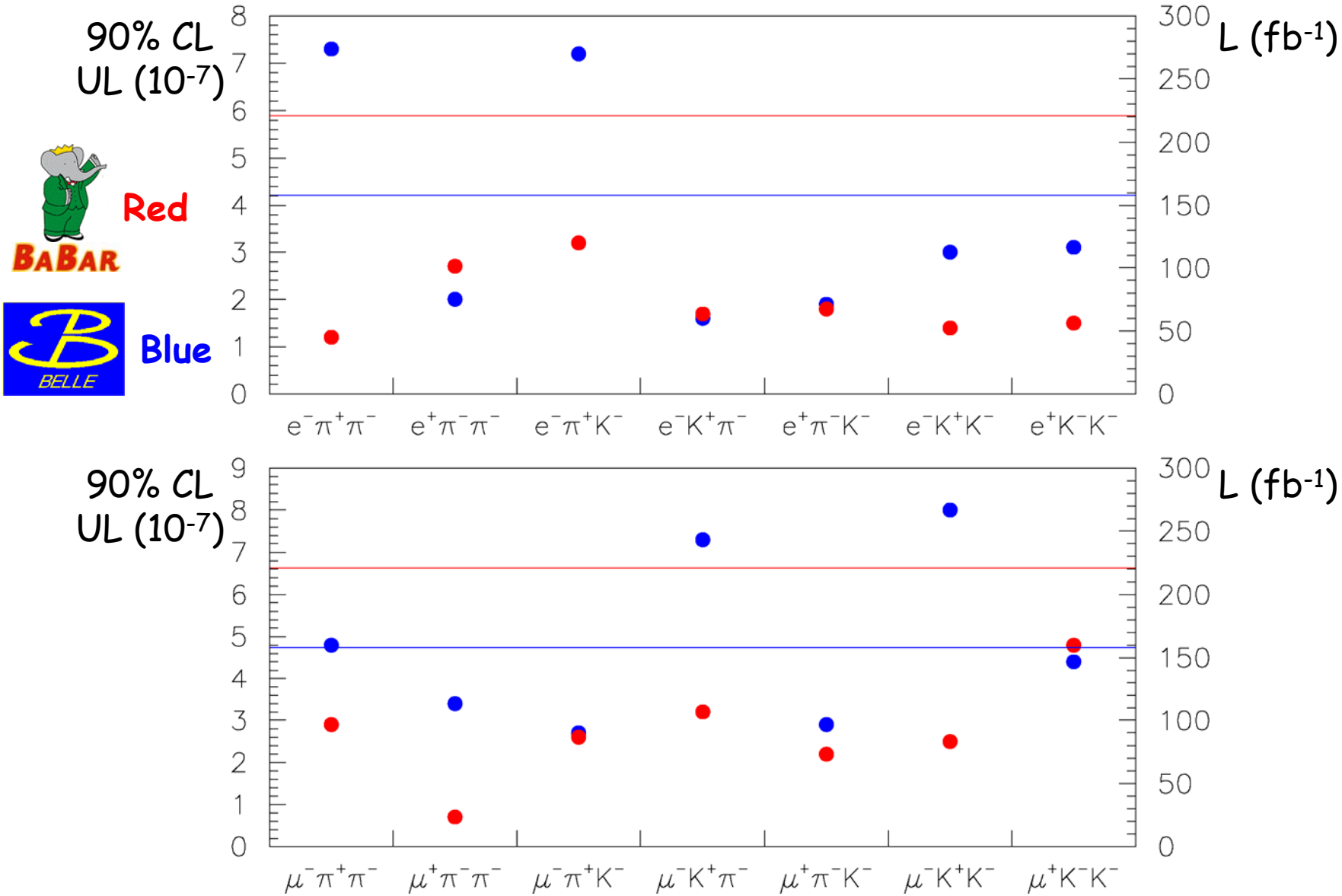
N_{bkgd}(tot) = 3.1

Observed (tot): 2

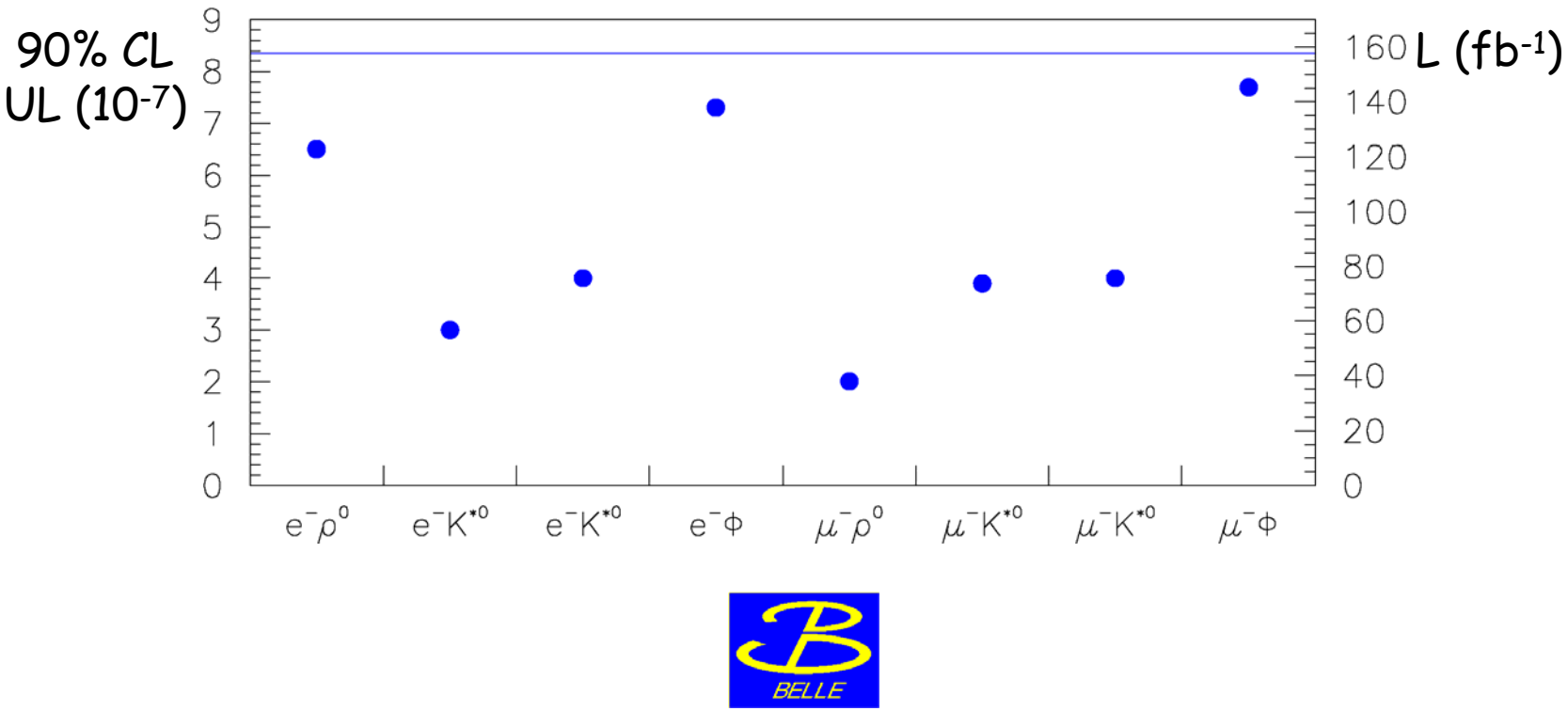
Summary of $\tau \to l\gamma$, $l\pi^0$, $l\eta$, $l\eta'$, lK^0_S



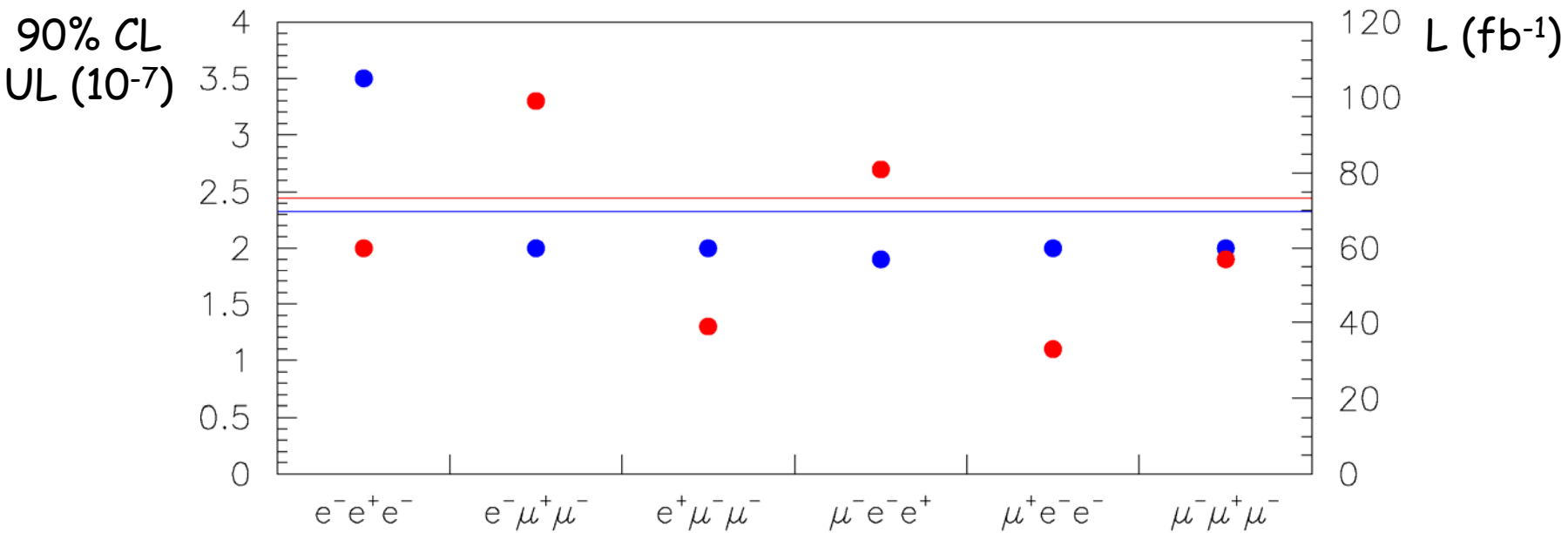
Summary of $\tau \to lhh'$



Summary of $\tau \to l\, V^0$



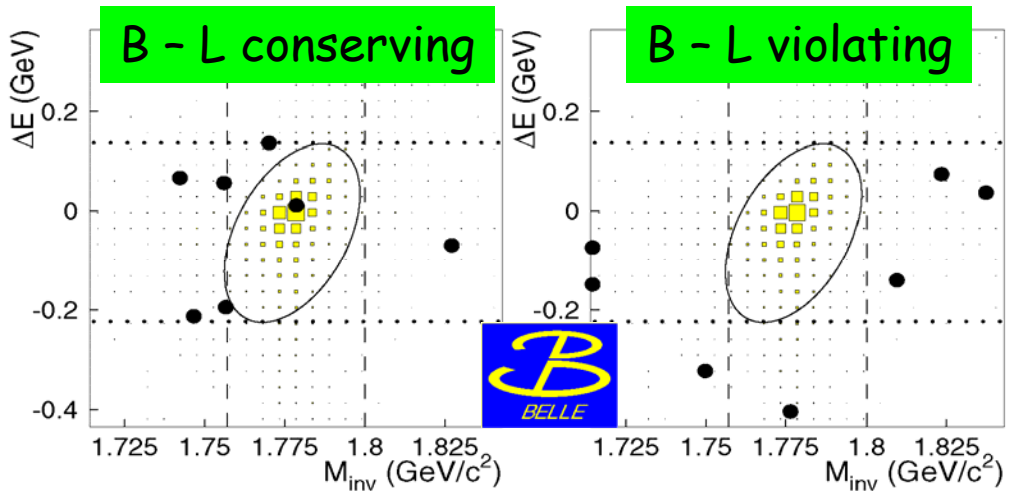
Summary of $\tau \to lll$



BABAR Red

BELLE Blue

Search for Lepton and Baryon Number Violation



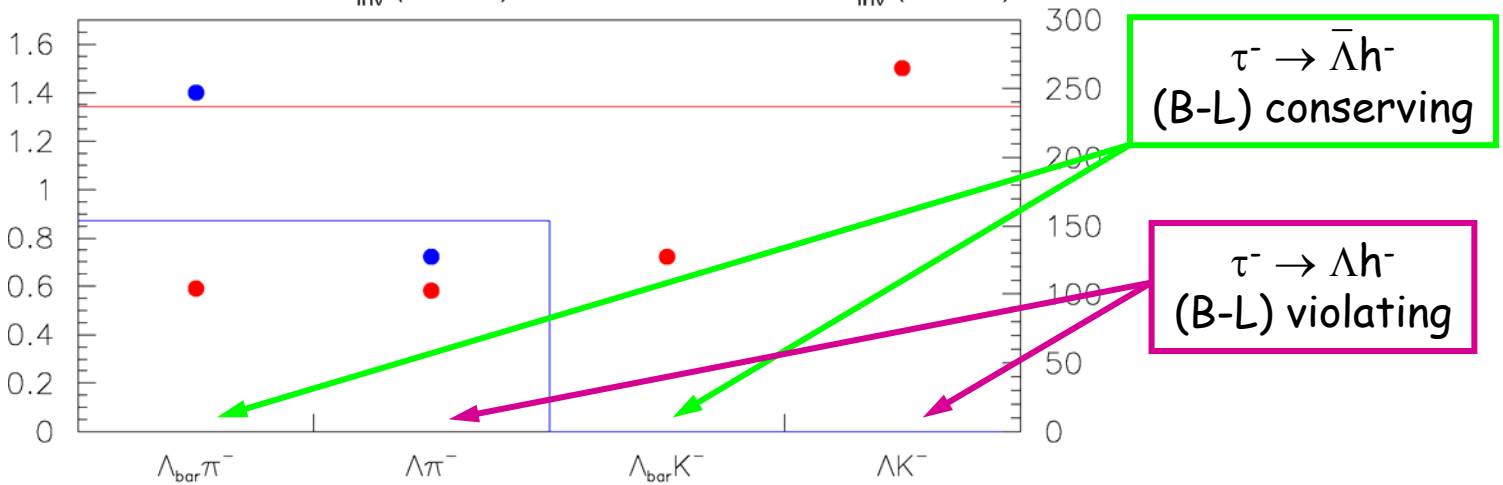
90% CL UL (10^{-7})

Red

BABAR (preliminary)

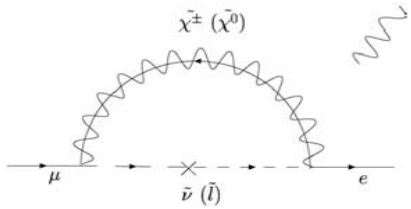
hep-ex/0607040

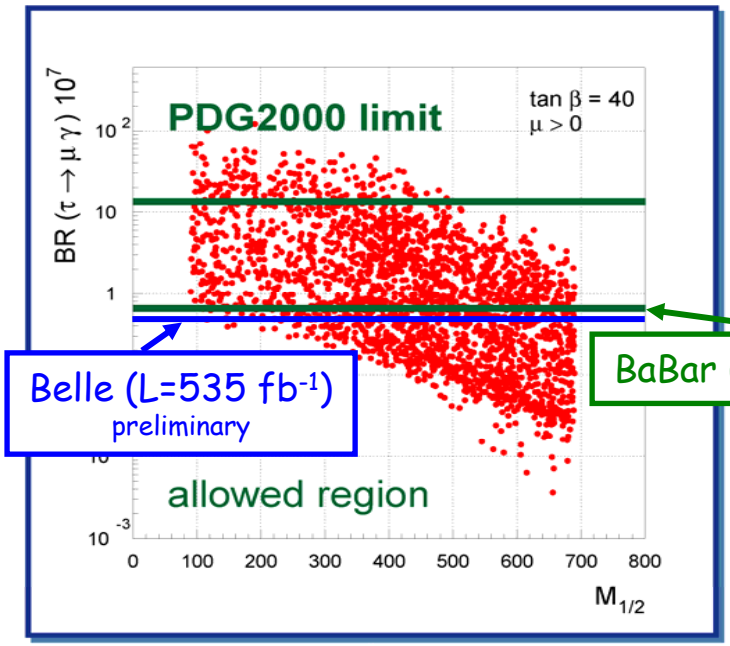
Blue



Current exp UL's vs BSM scenarios

$\tau \to \mu\gamma$



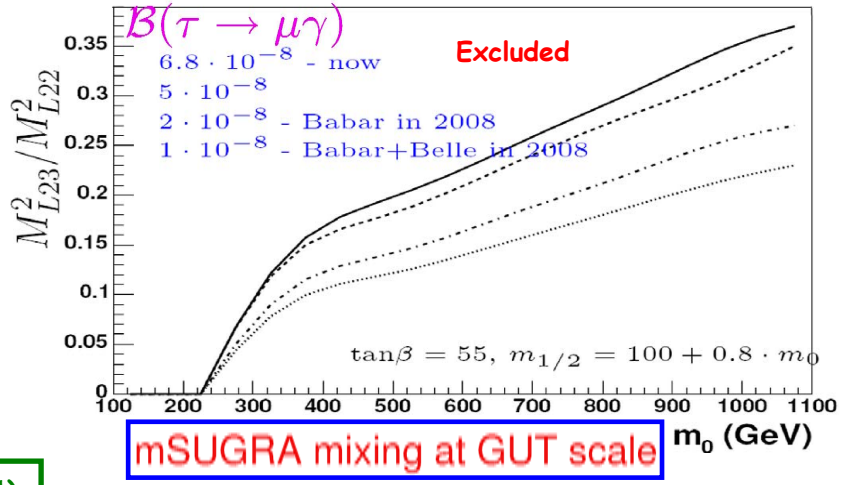


Belle (L=535 fb^{-1})
preliminary

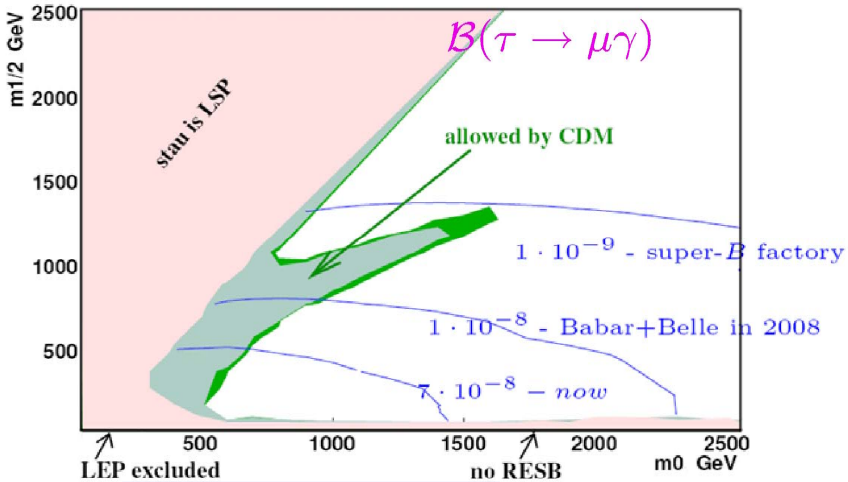
BaBar (L=211 fb^{-1})

SUSY SO(10) + seesaw
Masiero et al. – NJP 6 (2004) 202

$$BR(l_j \to l_i\gamma) \approx \frac{\alpha^3 \left|\delta^l_{ij}\right|^2}{G_F^2 m_{SUSY}^4} \tan^2\beta$$



mSUGRA mixing at GUT scale



mSUGRA + Seesaw

LFV in tau decays
How far we can go?

- It depends on the residual background level…
  - $\tau \to l\gamma$

    sensitivity currently **bkgd limited**

    expect sensitivity to scale as $1/\sqrt{L}$

    $\tau^- \to l^- \nu_\tau \bar{\nu}_l \gamma$ irreducible

    mass & energy resolution is important

  - $\tau \to lll$, lhh'

    sensitivity **not bkgd limited**

    expect sensitivity to scale as 1/L

Conclusions

- Searches for LFV in τ decays are an optimal hunting ground for BSM physics
  - complementary to possible LHC discoveries: observation or non observation of LFV processes in the charged sector can significantly constrain theory parameter space
- BaBar and Belle have looked for signals of LVF in many exclusive τ decay modes
  - No signal found yet
- Limits have pushed into the 10^{-8} region and parameter space in BSM scenarios is been eaten
- Look forward to interesting limits (or better…) from combined BaBar & Belle dataset
- Solid physics case for a future Super B factory

Backup slides

Summary of 90%CL Upper Limits on LFV τ decays

Channel	Belle		BaBar	
	Br (10^{-7})	$\mathcal{L}$ (fb^{-1})	Br (10^{-7})	$\mathcal{L}$ (fb^{-1})
$\mu^-\gamma$	<0.5*	535	<0.7	232
$\mu^-\pi^0$	<1.2	401	<1.1	339
$\mu^-\eta$	<0.7	401	<1.5	339
$e^-\gamma$	<1.2*	535	<1.1	232
$e^-\pi^0$	<0.8	401	<1.3	339
$e^-\eta$	<0.9	401	<1.6	339
$\ell\ell\ell$	<(2-4)	87	<(1-3)	92
$\ell hh'$	<(2-16)	158	<(1-5)	221

* preliminary

Summary of $\tau \to \ell$ Pseudo Scalar 90%CL Upper Limits

τ^- Decay Mode	Belle * Phys.Lett.B639:159-164,2006 hep-ex/0609013		BaBar PRL 98.061803 (2007)	
	Br 10^{-7}	Lum. fb^{-1}	Br 10^{-7}	Lum. fb^{-1}
$e^- K^0_S$	<0.56*	281		
$\mu^- K^0_S$	<0.49*	281		
$\mu^- \pi^0$	<1.2	401	<1.1	339
$\mu^- \eta$	<0.65	401	<1.5	339
$\mu^- \eta'$	<1.3	401	<1.4	339
$e^- \pi^0$	<0.8	401	<1.3	339
$e^- \eta$	<0.92	401	<1.6	339
$e^- \eta'$	<1.6	401	<2.4	339

Summary of $\tau \to \ell hh'$ 90%CL Upper Limits

τ^- mode	Belle Phys.Lett.B640:138 144,2006		BaBar PRL95(2005)191801	
	Br, 10^{-7}	Lum. fb^{-1}	Br, 10^{-7}	Lum. fb^{-1}
$e^-\pi^+\pi^-$	<7.3	158	<1.2	221
$e^+\pi^-\pi^-$	<2.0	158	<2.7	221
$e^-\pi^+K^-$	<7.2	158	<3.2	221
$e^-\pi^-K^+$	<1.6	158	<1.7	221
$e^+\pi^-K^-$	<1.9	158	<1.8	221
$e^-K^+K^-$	<3.0	158	<1.4	221
$e^+K^-K^-$	<3.1	158	<1.5	221

Summary of $\tau \to \ell$ Vector 90%CL Upper Limits

Phys.Lett.B640:138 144,2006

τ^- mode	Belle		τ^- mode	Belle	
	Br, 10^{-7}	Lum. fb^{-1}		Br, 10^{-7}	Lum. fb^{-1}
$e^-\rho^0$	<6.4	158	$\mu^-\rho^0$	<2.0	158
$e^-K^*(892)^0$	<3.0	158	$\mu^-K^*(892)^0$	<3.9	158
$e^-\overline{K^*}(892)^0$	<4.0	158	$\mu^-\overline{K^*}(892)^0$	<4.0	158
$e^-\phi$	<7.4	158	$\mu^-\phi$	<7.7	158