A search for $\tau \to \ell\gamma$ at Belle

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Introduction

Introduction

$$\tau \to \ell\gamma \quad (\ell = \mu, e)$$

- immeasurably small branching fraction via SM processes
- lepton flavour violation (LFV) is predictd to appear in a wide variety of New Physics (NP) processes
- of the τ processes, decays $\tau \to \ell\gamma$ predicted to be most dominant

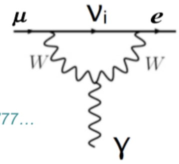
Introduction

E.g.: $\boxed{\mu \to e\gamma}$

$$\boxed{Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M_W^2}\right|^2 < 10^{-54}}$$

Petcov'77, Marciano & Sanda'77, Lee & Shrock'77…

$$\left[Br(\tau \to \mu\gamma) < 10^{-40}\right]$$



- In the SM with massive neutrinos, the LFV vertices are tiny due to GIM suppression!
- LFV has unobservably small rates via these processes

Introduction

Observation of LFV of this type would be
an unambiguous signature of NP!

Obligatory Belle slides

Obligatory Belle slides

Literature Review: $\tau \to \ell\gamma$ search

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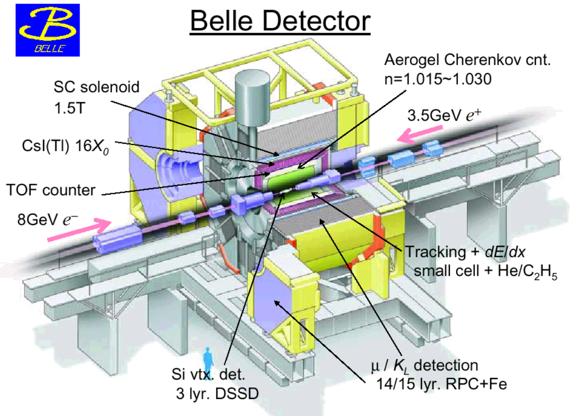


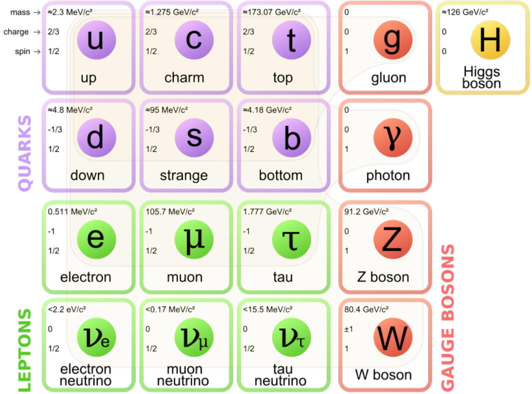
Obligatory Belle slides

- Belle experiment ran from 1998-2011 and collected $1000\,\text{fb}^{-1}$ of data
- e^+e^- asymmetric beam collider (8 GeV and 3.5 GeV)
- can produce other tau-pairs via

$$e^+e^- \to \tau^+\tau^-$$

The Standard Model

Standard Model (SM)



Standard Model (SM)

- SM predicts charge-parity (CP) conservation
- SM predicts massless neutrinos
- Both these are experimentally violated

Beyond the Standard Model

Beyond the Standard Model - CP Violation

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Beyond the Standard Model - Neutrino masses

- Nobel Prize awarded in 2015 for "*the discovery of neutrino oscillations, which shows that neutrinos have mass*"
- SM does not predict massive neutrinos
- We need NP to explain neutrino mass generation
- These NP mechanisms introduce LFV!

Motivation

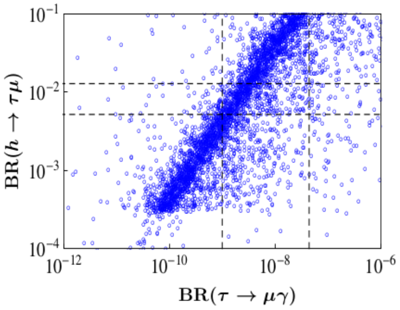
Motivation for the search

- LFV probes GUT scale loops (high mass)
- LFV is automatically introduced by neutrino mass generation mechanisms
- Anomalies!

Anomalies

Anomaly #1: CMS Higgs excess ($h \to \tau\mu$)

- CMS detected a 2.4σ excess in the branching fraction of $h \to \tau\mu$
- *Aristizabal Sierra, D.* and *Vicente, A.* (2014) propose an explanation of the excess
  - Type-III Two Higgs Doublet Model (2HDM)



Anomaly #2: Neutrino masses

- in the SM with massive neutrinos, LFV is heavily suppressed by neutrino mass, proportional to GIM factor $\left(\frac{m_\nu}{M_W}\right)^2$

  - W and ν in the SM with $\Lambda_{NP} \equiv M_R \equiv \Lambda_{see-saw}$

$$Br(\mu \to e\gamma) \sim \frac{v^4}{M_R^4} \leq 10^{-50} \qquad \textbf{GIM}$$

  - If $\Lambda_{NP} \ll \Lambda_{see-saw}$ ($\Lambda_{NP} \equiv m_{susy}$ in the MSSM)

$$Br(\mu \to e\gamma) \sim \frac{v^4}{\Lambda_{NP}^4}$$

Lepton-Flavour Changing Processes

Lepton-Flavour Changing Processes - Overview

- LFV is introduced in NP by neutrino mass generation mechanisms
- Some major models include ???
-

Other searches

Literature Review: $\tau \to \ell\gamma$ search

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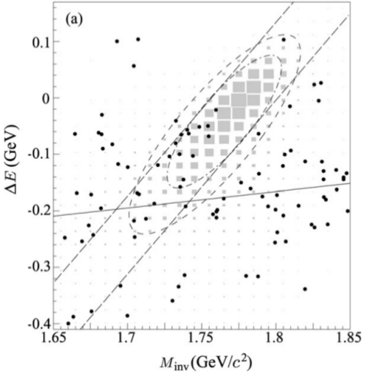
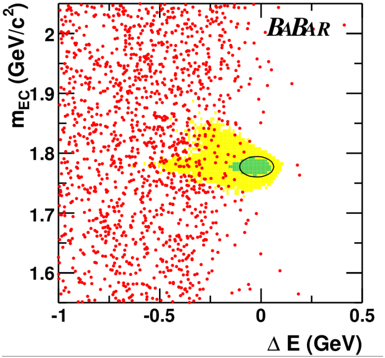
Other searches - overview

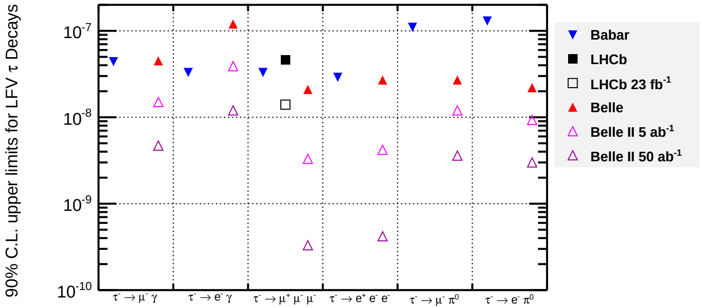
- Belle (2007)
  - $\mathcal{B}(\tau^- \to \mu^-\gamma) < 4.5 \times 10^{-8}$
  - $\mathcal{B}(\tau^- \to e^-\gamma) < 12 \times 10^{-7}$
- BaBar (2010)
  - $\mathcal{B}(\tau^- \to \mu^-\gamma) < 4.4 \times 10^{-8}$
  - $\mathcal{B}(\tau^- \to e^-\gamma) < 3.3 \times 10^{-8}$

Other searches - overview





Other searches - overview



Current progess

Current progress - selection


```
//Selection criteria - defining the cuts
                        //Bhabha and mumu suppression
const int cut0  = ( p_muCM.P() < 4.5 );
const int cut1  = ( p_tagtrackCM.P() < 4.5 );
const int cut2  = ( p_mu.Pt() > 0.1 );
const int cut3  = ( p_tagtrack.Pt() > 0.1 );
const int cut4  = ( ( -0.866 < TMath::Cos( p_mu.Theta() ) )
                                        && ( TMath::Cos( p_mu.Theta() ) < 0.956 ) );
const int cut5  = ( ( -0.866 < TMath::Cos( p_tagtrack.Theta() ) )
                                        && ( TMath::Cos( p_tagtrack.Theta() ) < 0.956 ) );
const int cut6  = ( p_gamma.E() > 0.1 );
const int cut7  = ( p_totalCM.E() < 11 );

                        //Mumu and qq suppression
const int cut8  = ( 0.9 < signalThrust && signalThrust < 0.98 );

                        //Particle identification
                                // Signal muon/electron
const int cut9  = (isEventMu) ? ( signalPID > 0.95 ) : ( signalPID > 0.9 );
const int cut10 = ( p_mu.P() > 1.0 );

                                // Tag not-muon/not-electron
const int cut11 = (isEventMu) ? ( tagPID < 0.8 ) : ( tagPID < 0.1 );


                                //Signal photon
const int cut12 = ( p_gamma.E() > 0.5 );
const int cut13 = ( ( -0.602 < TMath::Cos( p_gamma.Theta() ) )
                                        && ( TMath::Cos( p_gamma.Theta() ) < 0.829 ) );
```

24 selection criteria, taken from previous Belle search (currently unoptimised).

Literature Review: $\tau \to \ell\gamma$ search

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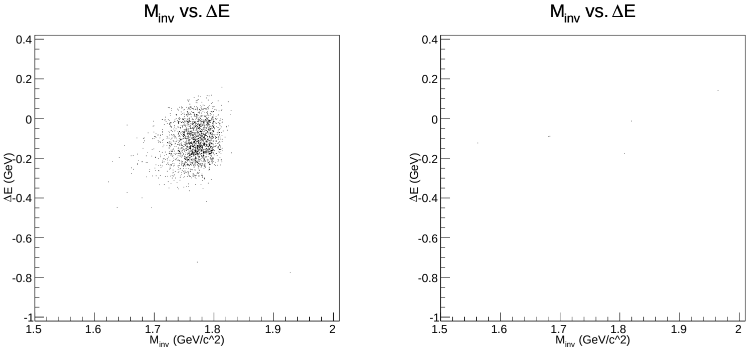
Current progress - selection

```
                        //Rejecting tautau background with Pi0's
const int cut14 = ( ( 0.4 < TMath::Cos( opening_mugammaCM ) )
                                        && ( TMath::Cos( opening_mugammaCM ) < 0.8 ) );


                        //Rejecting mumu events
const int cut15 = ( p_sumCM.E() < 9.0 );

                        //Removing mu gamma combinations from BG
const int cut16 = ( opening_tracksCM  > TMath::Pi()
const int cut17 = ( TMath::Cos( opening_taumu ) < 0.4 );

                        //Constraints on missing particles
const int cut18 = ( p_missing.P() > 0.4 );
const int cut19 = ( ( -0.866 < TMath::Cos( p_missing.Theta() ) )
                                        && ( TMath::Cos( p_missing.Theta() ) < 0.956 ) );
const int cut20 = (isEventMu) ?
        ( ( 0.4 < TMath::Cos( opening_missingtagCM ) )
                        && ( TMath::Cos( opening_missingtagCM ) < 0.98 ) ) :
        ( ( 0.4 < TMath::Cos( opening_missingtagCM ) )
                        && ( TMath::Cos( opening_missingtagCM ) < 0.99 ) );
const int cut21 = ( ( p_missing.P() > -5*m_miss2 - 1 ) && ( p_missing.P() > 1.5*m_miss2 - 1 ) );

                        //Constraints on missing neutrinos (tag side missing particles)
const int cut22 = (isEventMu) ?
        ( ( -1.0 < m_nu2 ) && ( m_nu2 < 2.0 ) ) :
        ( ( -0.5 < m_nu2 ) && ( m_nu2 < 2.0 ) );

                        //An additional cut on number of tracks
const int cut23 = ( nTracks == 2 || nTracks == 4 );
```

24 selection criteria, taken from previous Belle search (currently unoptimised).

Current progress - fitting region



We will select a region in our M_{inv} vs. ΔE plots as our Grand Signal Region (where events will be selected from data.

Summary

Thanks.