Searches for heavy neutrinos, LFV

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Introduction

- LHCb for rare searches
- Search for LFV in $D^0 \rightarrow e^\pm \mu^\mp$
- Search for LFV in $\tau^- \rightarrow \mu^- \mu^+ \mu^-$
- Search for Majorana neutrinos in $B^- \rightarrow \pi^+ \mu^- \mu^-$
- Summary
LHCb as flavour factory

- pp collisions at 7, 8 TeV
- Full spectrum of B hadrons
  - $B^0$, $B_s^0$, $B^+$, $B_c$, $L_b^0$, ...
  - And c hadrons too
- $\mathcal{L} \sim 10^{32} - 10^{33}$ cm$^{-2}$s$^{-1}$
- $\int \mathcal{L} = 3.0$ fb$^{-1}$ in Run I

- Single arm forward spectrometer
- Acceptance $2 < \eta < 5$
- Momentum resolution:
  - $\delta p/p \sim 0.5 - 1\%$
- IP resolution $\sim 20\mu$m
- Excellent pid, trigger, ...
LHCb in Run II

- p-p collisions at 13 TeV
- \( \mathcal{L} \sim 10^{32} - 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)
  - Luminosity levelling
  - Average Interactions / bunch crossing \( \sim 1 \)
- Aim for 8 pb\(^{-1}\)
- Precision measurements using high statistics
- Redesigned trigger
  - Automatised calibration and alignment
  - Offline rate of \( \sim 12.5 \text{ Khz} \)
    - 600 MB/s to storage
- Note - results presented today use only Run I data
Motivation

- Neutrino oscillations
  - Only possible with massive neutrinos
    - Needs SM extensions
    - e.g. see-saw mechanism, with heavy neutrinos

- LFV
  - Suppressed in SM (BF $\lesssim 10^{-40}$)
  - Contributions from $\nu$ oscillations

- Interesting ground for studies
  - Difficult to detect $\nu$ directly
  - Test for properties indirectly using precision studies
  - Modifications in rates from SM extensions
LFV decay $D^0 \rightarrow e^\pm \mu^\mp$

- Forbidden in SM
  - $2.6 \times 10^{-7}$ (90%CL) from Belle
    - PRD 81 (2010) 091102
- Possible for various SM extensions
  - BR $\sim 10^{-6}$ for R-parity violating SUSY models
  - $\sim 10^{-8}$ for some leptoquark models
  - $\sim 10^{-14}$ for SM with extra fermions
LFV decay $D^0 \rightarrow e^\pm \mu^\mp$

- Analysis using Run I data
  - 3 fb$^{-1}$, $\sqrt{s} = 7–8$ TeV
  - Use $D^0$ from $D^{*+} \rightarrow D^0\pi^+$
  - Normalisation channel:
    $D^0 \rightarrow K^-\pi^+$

- Standard LHCb blind analysis
  - Pre-selection + MVA
  - Evaluate backgrounds
    - $\pi^+\pi^-$, $\pi^+e^+\nu_e$, $\pi^-\mu^+\nu_\mu$
  - Understand systematics
  - Unblind and extract fit values
    - Fit 3 bins of BDT output
    - 2D fit for $\Delta m$, $m$
  - Plot: Most signal-like BDT bin
LFV decay $D^0 \rightarrow e^\pm \mu^\mp$

Upper limit on BF

- $1.3 \times 10^{-8}$ (90%)
- $1.6 \times 10^{-8}$ (95%)
- Dominated by statistics
LFV decay $\tau^- \rightarrow \mu^- \mu^+ \mu^-$

- Large inclusive $\tau$ cross-section
  - From decays of $c$, $b$ hadrons
  - $\sim 85 \mu$b at 7 TeV

- Analysis based on Run I data
  - $3 \text{ fb}^{-1}$, $\sqrt{s} = 7$–8 TeV

- Typical LHCb selection
  - Three $\mu$ tracks which make up a $\tau$
  - Multiple MVAs
    - Separate optimizations for 2011 and 2012 data

- Normalised to
  - $D_s^- \rightarrow \phi(\mu^+ \mu^-) \pi^-$
LFV decay $\tau^- \rightarrow \mu^- \mu^+ \mu^-$

- No significant excess over background found

- Measured
  - $\text{BF} (\tau^- \rightarrow \mu^- \mu^+ \mu^-) < 4.6 (5.6) \times 10^{-8}$
  - 90 (95) % CL

- Expected
  - $\text{BF} (\tau^- \rightarrow \mu^- \mu^+ \mu^-) < 5.0 (6.1) \times 10^{-8}$
Majorana neutrinos in LHCb

- Neutrino masses from see-saw mechanism
  - Likely mass has Majorana component
  - Heavy \((m \gg eV)\), unstable

- Majorana neutrinos
  - Neutrino-less double beta decay
    - Can be probed in LHC
  - Pairs of identical leptons
    - LFV, LNV

- Studies complementary to those from ATLAS / CMS
Majorana neutrinos in $B^- \rightarrow \pi^+\mu^-\mu^-$

- **Search for neutrinos with**
  - $250 \text{ MeV} < M < 5000 \text{ MeV}$
  - Two samples:
    - $\tau < 1 \text{ ps}$
    - $1 \leq \tau < 1000 \text{ ps}$

- **Normalise to**
  $B^- \rightarrow J/\psi K^- \text{ where } J/\psi \rightarrow \mu^+\mu^-$

- **Analysis using Run I data**
  - $3 \text{ fb}^{-1}, \sqrt{s} = 7–8 \text{ TeV}$

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**Graphs:**

- **Norm Channel**
  - $m(J/\psi K^-) [\text{MeV}]$
  - $m(\pi^+\mu^+\mu^-) [\text{MeV}]$
  - $m(\pi^+\mu^+\mu^-) [\text{MeV}]$
Majorana neutrinos in $B^- \rightarrow \pi^+ \mu^- \mu^-$

- No signal found
- $BF(B^- \rightarrow \pi^+ \mu^- \mu^-) < 4 \times 10^{-9}$
- Also quote limits on coupling of 4th generation majorana neutrino to muons
Summary

- LHCb is an excellent b and c factory
  - Various searches for very rare decays performed
    - No signal so far
    - Various limits improved by \( \sim x10 \)
      - Starting to constrain some models
    - Still far from systematic wall
    - J. Prisciandaro talk on LU/LFV tests
  - Run II ongoing
    - Improved trigger system
      - L. Grillo talk on LHCb trigger and alignment
    - Larger data set than proportional to \( \mathcal{L} \)
  - Look forward to exciting times
    - A. Cardini talk on LHCb Upgrade
    - More analyses in future from LHCb for LFV / LNV tests