Lepton Flavour Violating decays in LHCb

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Outline

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   - Pati Salam model
2. $B^0_{d,s} \to e^\pm \mu^\mp$
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3. $B^0_{d,s} \to \mu^\pm \tau^\mp$
   - Theory
   - Selection
   - LHCb Sensitivity
4. Conclusions

Lepton Flavour Violation

Standard Model

The lepton family number and the total lepton number
are strictly conserved in SM!

Note: Taking into accout neutrino oscillations
LFV reactions could be allowed but with extremely small probabilities.

Beyond Standard Model

Many models beyond the SM allow LFV, two main cathegories:

- Supersimmetry Theories
- Grand Unification Theories

LFV in Supersymmetry

Symmetry between bosons and fermions

- Supersymmetry (SUSY) is broken at currently studied energy scale
- SUSY does not include directly Lepton Flavour Violating sources

Still

Since $m_\nu \neq 0$, heavy right-handed neutrinos could be incorporated in SUSY through the *Seesaw* mechanism

$\Rightarrow$ Giving rise to Higg-mediated LFV reaction at one-loop level.

Pati-Salam model

Pati Salam model

It belongs to Grand Unification Theories
Lepton number is thought as the fourth colour

If this is described by a local gauge simmetry:

$$SU(4) \rightarrow SU(3) \times U(1)$$

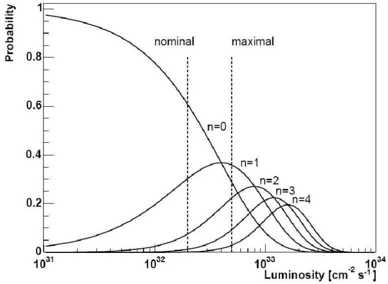
this leads to an interaction between leptons and quarks, mediated by new particles called Leptoquarks (LQ).

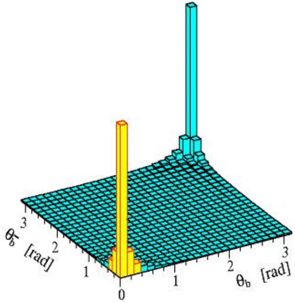
LQs have both lepton and barion number leading to LFV reations also at tree-level.
Of course M_{LQ} should be very high.

Notice: It's **not** compulsory to associate the first lepton generation to the first quark generation

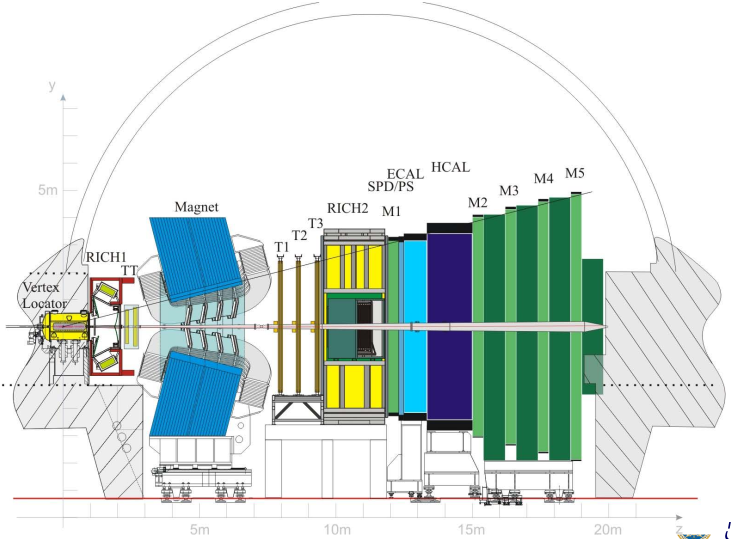
LHCb experiment

- LHC provides p-p collisions at 14 TeV (center of mass energy).
- $b\bar{b}$ pairs are produces mainly in the forward (and backward) region
- LHCb detector is a single-harm spectrometer $(1.9 < \eta < 4.9)$
- Luminosity $(2 \cdot 10^{32} cm^{-2} s^{-1})$ is tuned to have 1 interaction per bunch-crossing
- 10^{12} B hadrons per year



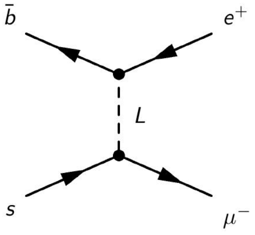


LHCb detector

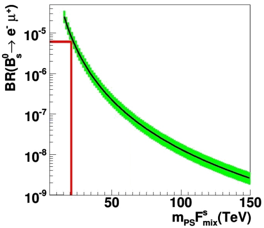


$B^0_{d,s} \to e^\pm\mu^\mp$decay

In the frame of Pati Salam Model is forseen the $B^0_{d,s} \to e^\pm\mu^\mp$ decay



(c) Feynman Diagram for $B^0_s \to e^\pm\mu^\mp$ decay



(d) Branching Ratio as a function of Leptoquark mass.

$$BR(B^0_{d,s} \to e^\pm\mu^\mp) \propto \frac{\tau_{B(d,s)}}{h}\alpha_S^2(M_{LQ})\frac{f^2_{B(s,d)}m^3_{B(s,d)}(F^{d,s}_{mix})^2}{M^4_{LQ}}$$

Present limit for $B^0_s \to e^\pm\mu^\mp$: $BR < 6.1 \cdot 10^{-6}$ (CDF)
Present limit for $B^0_d \to e^\pm\mu^\mp$: $BR < 9.2 \cdot 10^{-8}$ (BaBar) [1]

[1] http://indico.cern.ch/conferenceDisplay.py?confId=29335

$B^0_{d,s} \longrightarrow e^{\pm}\mu^{\mp}$

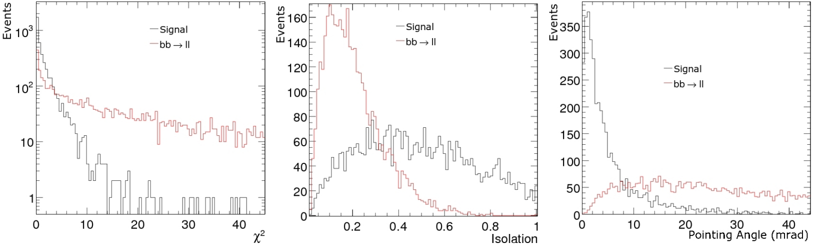
Signal: Sample of $B^0_s \rightarrow e^{\pm}\mu^{\mp}$assuming the same efficiency for B^0_d.

Background:

- Di-lepton (main background): $b\bar{b} \rightarrow e^{\pm}\mu^{\mp}$ where an electron and a muon come from two B hadrons that decay semileptonically.
- Hadronic two body: $B(\Lambda_b) \rightarrow h^+_a h^-_b$ where $h = \pi, K, p$, with misidentification of hadrons.
- Other specific channels: $B^+ \rightarrow J/\psi K^+$ or $B^+_c \rightarrow J/\psi \mu^+ \nu$.

$B^0_{d,s} \to e^{\pm}\mu^{\mp}$selection

Selection variables:



(e) B vertex χ^2

(f) Isolation $I_B = \frac{p_T(B^0_s)}{p_T(B^0_s)+\sum_i (p_T)_i}$

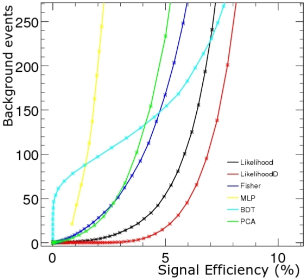
(g) Pointing: $Angle(\vec{p}_B, \vec{r}_{BV} - \vec{r}_{PV})$

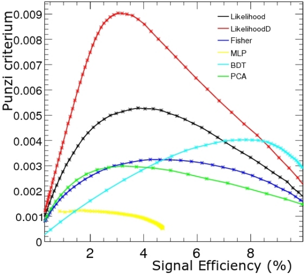
In addiction, selection on: $p_T(B)$, $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ between leptons, and the significance of vertices distance ($|r_{PV} - r_{BV}|/\sigma$).

$B^0_{d,s} \to e^\pm \mu^\mp$ selection

Multivariate analysis

Many different multivariate methods have been tried and tested, leading to the choice of a Decorrelated Likelihood that has shown the best results.



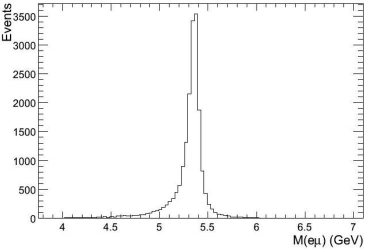


Optimal cut point has been chosen according to the following variable:

$$\Pi = \left(\frac{\varepsilon_{sig}}{a/2+\sqrt{N_{Bkg}}}\right)^{2}$$

[2] G. Punzi, physics/0308063

$B^0_{d,s} \to e^{\pm}\mu^{\mp}$LHCb sensisivity



Selection

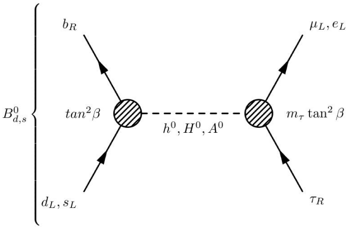
- Decorrelated Likelihood
- Identification cuts
- $|M(\mu e) - M_{B^0_s}| < 100$ MeV

Upper limit

Upper limit on signal Branching Ratio in case only background is observed:
$BR(B^0_s \to e^{\pm}\mu^{\mp}) = 1.3 \cdot 10^{-8}$ at 90 % CL
$BR(B^0_d \to e^{\pm}\mu^{\mp}) = 3.2 \cdot 10^{-9}$ at 90 % CL

$B^0_s \to \mu^\pm\tau^\mp$decay

Still not allowed at tree level in SUSY: allowed including loops



$$BR(B^0_s \to \mu^\pm\tau^\mp) \simeq 3.6 \cdot 10^{-7} \left(\frac{\tan\beta}{60}\right)^8 \left(\frac{100\,GeV}{M_A}\right)^4$$ [3]

Current experimental bound: $BR(B^0_s \to \mu^\pm\tau^\mp) < 2.2 \cdot 10^{-5}$ (BaBar)[4]

Note: within this frame $B^0_{d,s} \to e^\pm\mu^\mp$is constrained by $\mu \to e\gamma$ decay below experimental sensitivity.

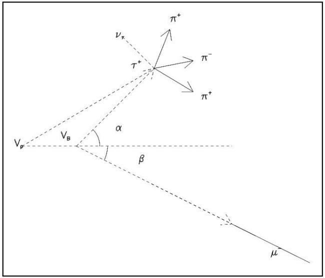
[3] arXiv:hep-ph/0209207v1

[4] http://indico.cern.ch/conferenceDisplay.py?confId=29335

$B^0_s \to \mu^\pm\tau^\mp$

Signal detection is the first challenging problem:

Choose decays for which $\tau \to 3\pi + \nu_\tau$ (10%)
$\Rightarrow$ Give up most of the signal but can reconstruct τ vertex.



- The τ and the primary vertices and the μ trajectory are on a same plane.
- The continuation of μ trajectory intercepts the line joining these two vertices
- The B^0_s decay vertex is located on the μ trajectory.

A sample of $B^0_s \to \mu^\pm\tau^\mp$ has been generated requiring the B within LHCb acceptance and the τ to decay in $3\pi + \nu$.

- Require only one primary vertex
- Require Level 0 (L0) trigger and one High Level Trigger:

$B^0_s \to \mu^\pm\tau^\mp$ selection

τ vertex is formed with 3 pions

$\Rightarrow$ Lots of combinations per event (also in signal)
More: total reconstruction efficiency is lowered by the need of the 4 tracks.

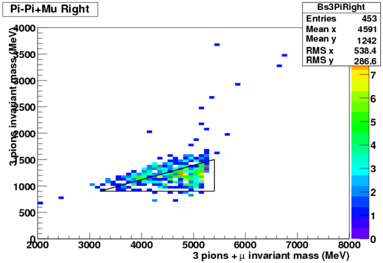
Criteria must be chosen in order to select the correct combination

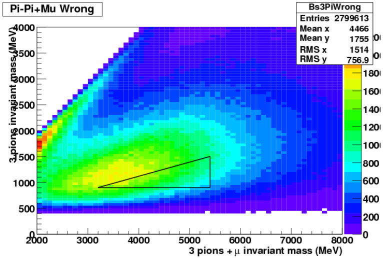
Geometry related variables

- Significance of the distance between Primary vertex and τ decay vertex
- χ^2 of vertex formed by three pions
- *Planarity* (Angle between planes)
- Impact parameter of muon with respect to
  - P. Vertex
  - τ Vertex

Kinematics related variables

- $M_{3\pi}$
- $M_{3\pi\mu}$
- Correlation of these.
- Cut on transverse momentum of pions





$B^0_s \to \mu^\pm\tau^\mp$: Background

Inclusive $b\bar{b}$

A sample of 672k of $b\bar{b}$ inclusive events has been studied:
applying the selection leads to 12 events left.

$\Rightarrow \varepsilon_{Bkg} = 1.8 \cdot 10^{-5}$

In $2fb^{-1}$ (one year of data taking) of integrated luminosity this means that one gets:
$N_{Bkg} = 7.7 \cdot 10^6$

$B^0_s \to \mu^\pm\tau^\mp$: results

Limit on Branching Ratio

Total signal efficiency for this analysis is 1.9 %

$BR(B^0_s \to \mu\tau) < 4.4 \cdot 10^{-5}$ at 90% CL

If $B^0_s \to \tau^+\mu^-$ and $B^0_s \to \tau^-\mu^+$ are both allowed the limit becomes $3.5 \cdot 10^{-5}$
For B^0_d the limit is better by a factor 4.

Improvements

If one assumes to have just a missing neutrino at τ vertex, (and not also a π^0) the decay is kinematically solvable.

Conclusions

LFV reactions are crucial clues for physics beyond the Standard Model

At LHCb will be possible to study LFV reactions such as $B^0_{d,s} \rightarrow e^{\pm}\mu^{\mp}$and $B^0_{d,s} \rightarrow \mu^{\pm}\tau^{\mp}$with improved sensitivities with respect to past experiments.

Tight limits on new physics theories parameters will be set in case of no signal events observation.

But of course we hope for signal observations!

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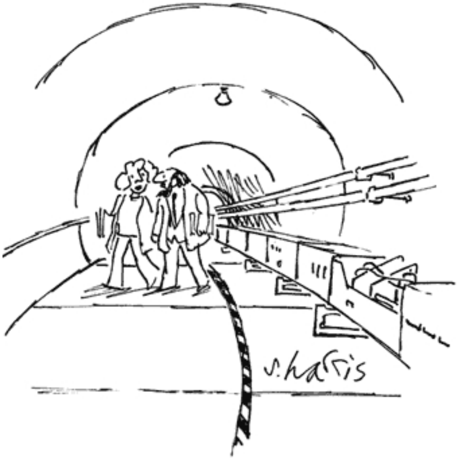

"WHAT IF WE SPEND ALL THESE BILLIONS, AND THERE JUST AREN'T ANY MORE PARTICLES TO FIND?"