Lepton-number and lepton-flavour violation in B decays

Phenomenology Symposium 2014

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on behalf of the LHCb collaboration

Overview

- Lepton-number violation - search for Majorana neutrinos
  - $B^- \rightarrow \pi^+ \mu^- \mu^-$

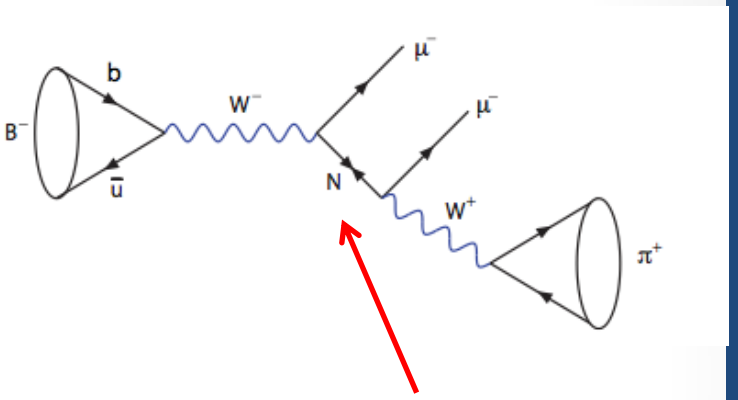
- Lepton-flavour violation
  - B_s^0 -> e μ and B^0 -> e μ
  - τ^- -> $\mu^+ \mu^- \mu^-$

Rare Decays at LHCb

- Currently no sign of New Physics from direct searches
- Decays that are forbidden in SM or have very small branching fractions allow to probe contributions from new processes/heavy particles at a scale beyond that of direct searches
- Rare decay measurements used to set constraints on theories beyond the SM
- LHCb particularly well suited for rare decay searches
  - Efficient triggering
  - Excellent particle identification
  - Precise vertexing (VELO)

Lepton-number violating decay
$B^- \rightarrow \pi^+ \mu^- \mu^-$

- $B^- \rightarrow \pi^+ \mu^- \mu^-$ decay forbidden by SM as violates conservation of lepton-number
- May proceed via production of Majorana neutrinos – similar to neutrinoless double beta decay
- Most sensitive B meson decay channel for Majorana searches



Here neutrino is its own antiparticle

- Sensitive to neutrino lifetimes up to 1000 ps and neutrino masses 250-5000 MeV
- Previous best measurement by LHCb (0.41 fb^{-1})

CLEO	$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 1400 \times 10^{-9}$	at 90% C.L. PRD65:111102(2002)
Babar	$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 107 \times 10^{-9}$	at 90% C.L. PRD85:071103(2012)
LHCb (0.41fb^{-1})	$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 13 \times 10^{-9}$	at 95% C.L. PRD85:112004(2012)

PRL 112, 131802

Analysis Method

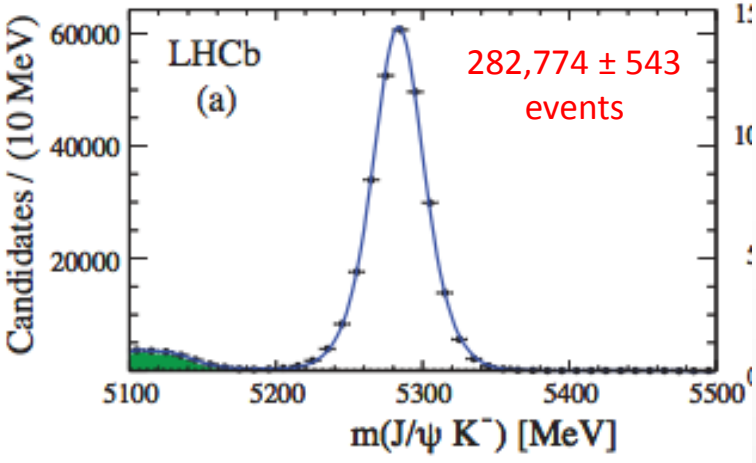
- Use full 3 fb^{-1} of data collected by LHCb at 7/8 TeV centre-of-mass energy
- Use normalization channel $B^- \rightarrow K^- J/\psi (\rightarrow \mu^+ \mu^-)$
- Split selection process based on neutrino lifetime:

  for short $\tau_N \leq 1$ ps (S)

  assume N has zero lifetime, B decay vertex formed by $\pi^+ \mu^- \mu^-$ i.e. $B^- \rightarrow \pi^+ \mu^- \mu^-$

  for long $\tau_N \leq 1000$ ps (L)

  $\pi^+ \mu^-$ vertex significantly detached from B, reconstruct B decay vertex and N decay vertex i.e. $B^- \rightarrow N(\pi^+ \mu^-) \mu^-$

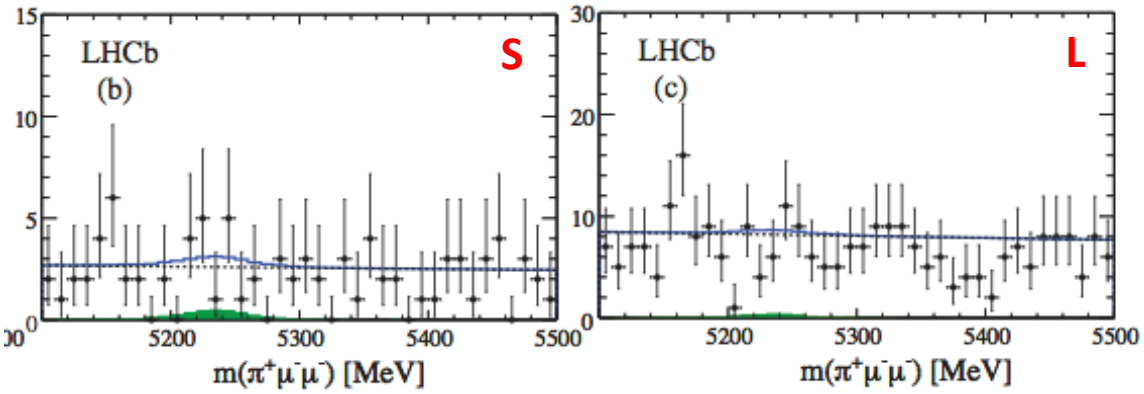


$B^- \rightarrow K^- J/\psi (\dashrightarrow \mu^+ \mu^-)$ normalization channel

PRL 112, 131802

Results

- No signal observed for either **S** or **L** selection channels

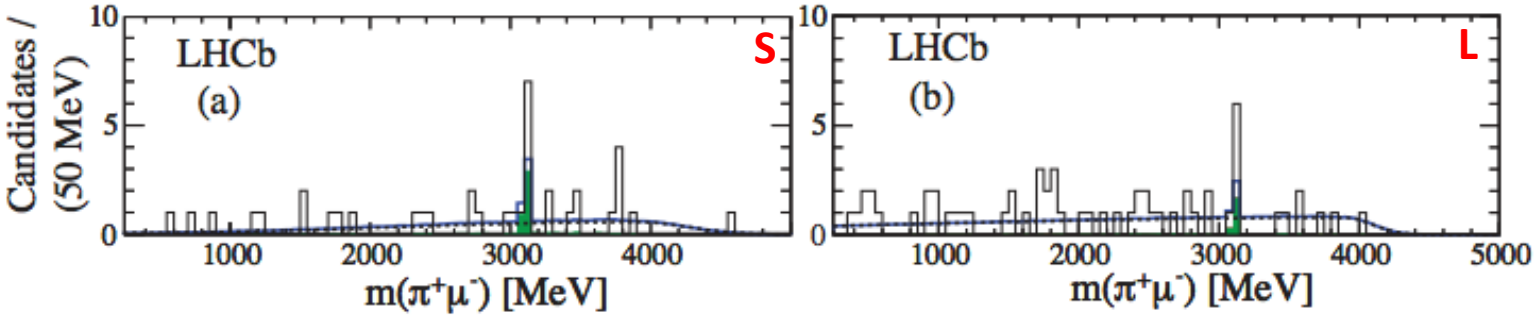


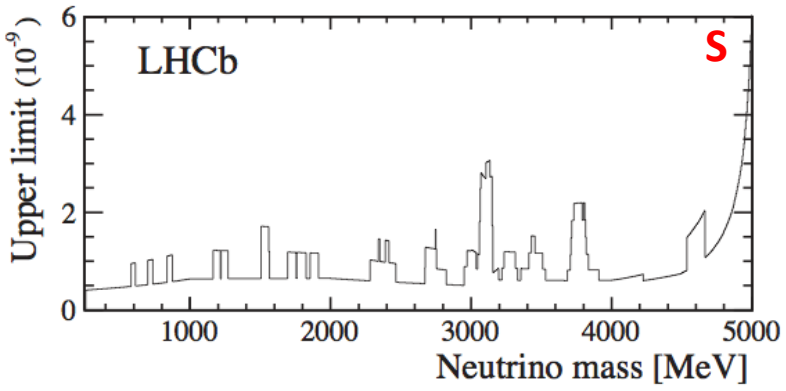
- Use CLs method to set upper limit on branching fraction [Nucl.Instrum.Meth. A434 (1999)]

$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 4.0 \times 10^{-9}$ at 95% C.L. **(S)** Best limit to date

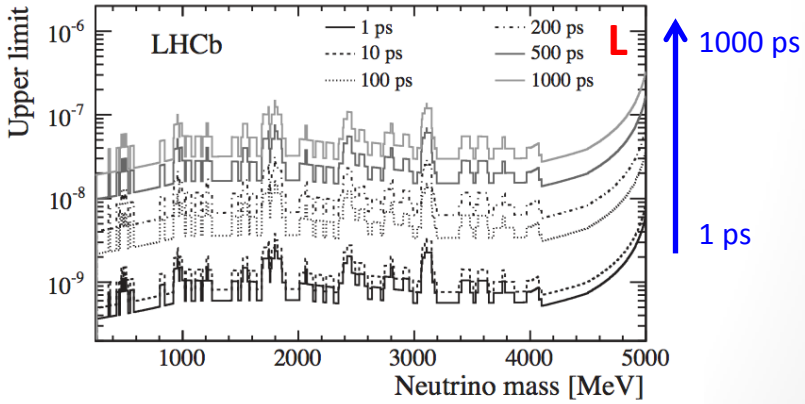
- Detection efficiency varies as a function of m_N and τ_N
- Calculate branching fraction upper limits (95% C.L.) as function of m_N **(S)** or m_N and τ_N **(L)**

Results





Branching fraction upper limits as a function of m_N



Branching fraction upper limits as a function of m_N and τ_N

Results

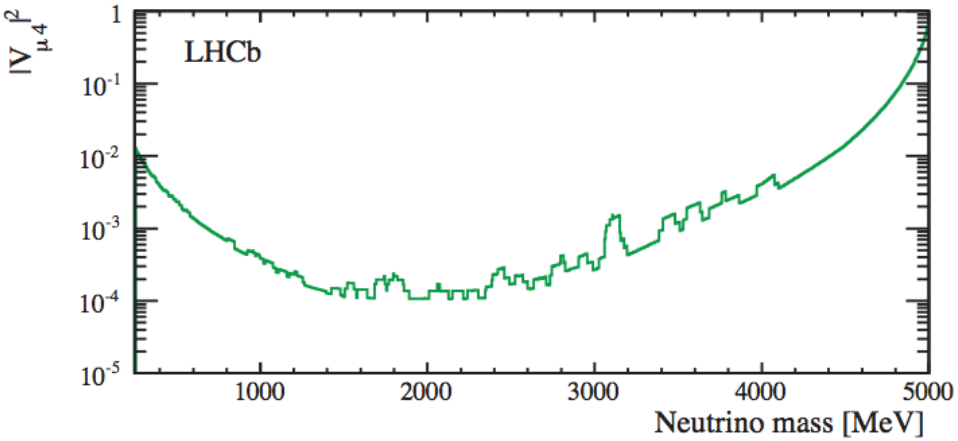
- Set upper limits on coupling of single 4th-generation Majorana neutrino to muons $|V_{\mu 4}|$, as function of m_N (95% C.L.)

$$\mathcal{B}(B^- \to \pi^+ \mu^- \mu^-) = \frac{G_F^4 f_B^2 f_\pi^2 m_B^5}{128\pi^2\hbar} |V_{ub}V_{ud}|^2 \tau_B \left(1 - \frac{m_N^2}{m_B^2}\right) \frac{m_N}{\Gamma_N} |V_{\mu 4}|^4$$

[JHEP05(2009)030]

where

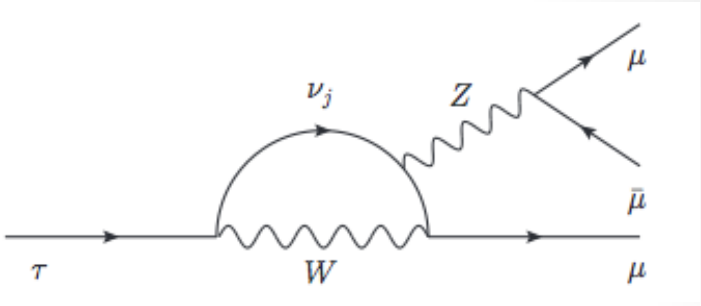
$$\Gamma_N = \left[3.95 m_N^3 + 2.00 m_N^5 (1.44 m_N^3 + 1.14)\right] 10^{-13} |V_{\mu 4}|^2$$



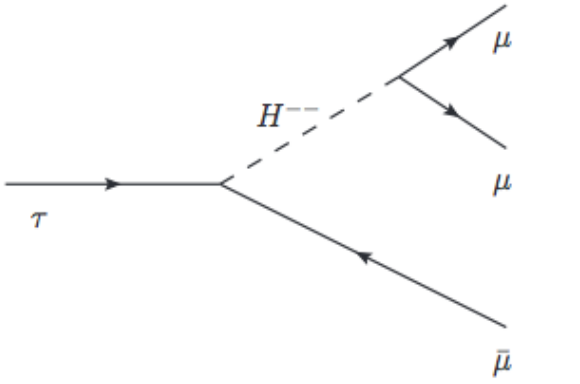
Lepton-flavour violating decays
$\tau^- \to \mu^+ \mu^- \mu^-$

- Decay forbidden in SM due to lepton-flavour conservation
- Observation of neutrino oscillations indicates charged LFV decays possible via loops, $\mathcal{B} < 10^{-40}$
- New physics can enhance branching fractions (e.g. new heavy particles entering loops, models with doubly charged Higgs) to as high ~ 10^{-7}
- Previous measurements at B factories

Belle	$\mathcal{B}(\tau^- \to \mu^+ \mu^- \mu^-) < 2.1 \times 10^{-8}$	at 90% C.L. [PLB 687(2010) 139]
Babar	$\mathcal{B}(\tau^- \to \mu^+ \mu^- \mu^-) < 3.3 \times 10^{-8}$	at 90% C.L. [PRD 81,111101(R) (2010)]



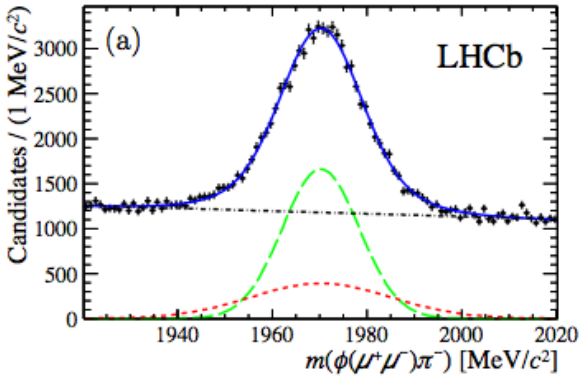
Electroweak penguin diagram for cLFV decay where neutrino flavour oscillates



Possible new physics decay involving doubly charged Higgs

Analysis Method

- Use 1 fb^{-1} of data collected by LHCb in 2011 at 7 TeV centre-of-mass energy
- LHCb collected ~ 8 x 10^{10} τ in detector acceptance in 2011 [PRB 724 (2013)]
- Normalization channel $D_s^- \rightarrow \phi (\mu^+ \mu^-) \pi^-$

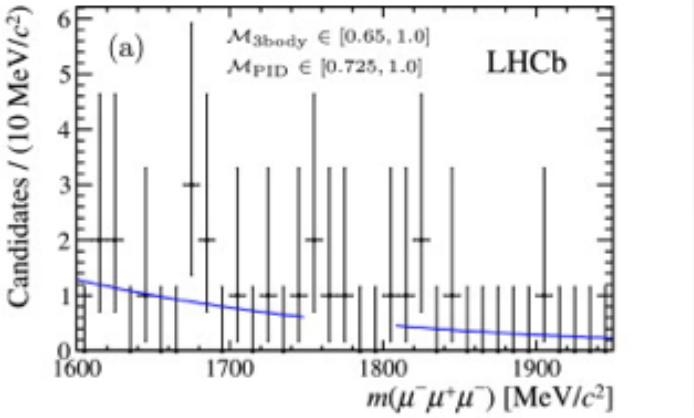


$D_s^- \rightarrow \phi (\mu^+ \mu^-) \pi^-$ normalization channel

- Study events in binned 3-D space:
  - Likelihood variable based on 3-body decay topology (BDT)
    Including vertex quality and displacement from primary vertex
  - Likelihood variable based on muon particle identification (Neural network)
    Including information from RICH, calorimeters, muon stations and kinematics
  - Invariant mass of τ^- candidate

Results

- Number of observed $\tau^- \to \mu^+ \mu^- \mu^-$ events compatible with background expectation

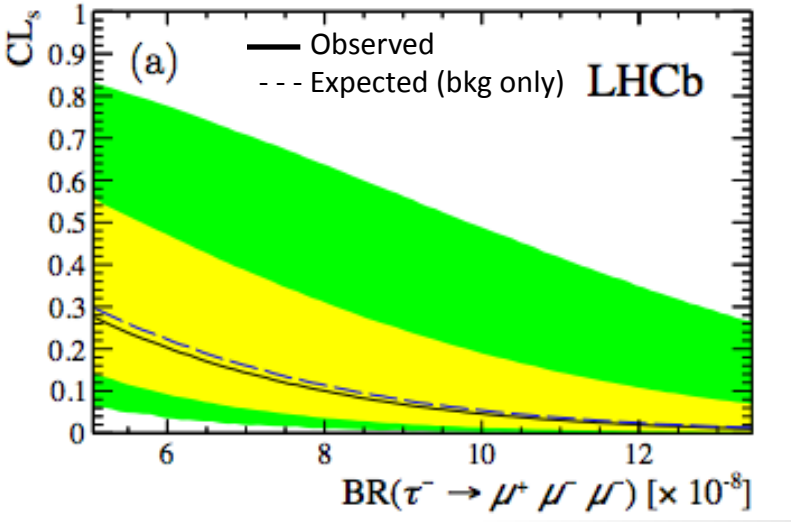


- Use CLs method to set upper limit on branching fraction

$\mathcal{B}(\tau^- \to \mu^+ \mu^- \mu^-) < 8.0\ (9.8) \times 10^{-8}$ at 90% (95%) C.L.

- First limit on $\tau^- \to \mu^+ \mu^- \mu^-$ obtained at a hadron collider

- Result compatible with limits set by Belle, expect 50 fb^{-1} post upgrade

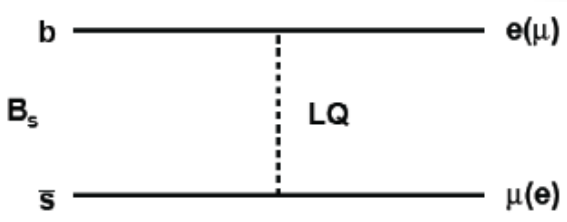


PLB 724 (2013) 36-45

Lepton-flavour violating decays B_s^0 -> e μ and B^0 -> e μ

- B_s^0 -> e μ and B^0 -> e μ forbidden by lepton-flavour conservation in SM

- Allowed in BSM models such as SUSY and **Pati-Salam Leptoquark model** [Phys. Rev. D 10(1974) 275]



B_s^0 -> e μ proceeding via leptoquark

- Prediction of new interaction between leptons and quarks mediated by spin-1 gauge boson **leptoquark**

- Direct production searches for leptoquarks at ATLAS and CMS – only leptoquarks coupling quarks and leptons of same generation

  Lower bounds on leptoquark masses in range >0.4 to >0.9 TeV/c^2 PRD 83 (2011) 112006 PRD 86 (2012) 052013

- These indirect searches probe leptoquarks which couple quarks and leptons from different generations

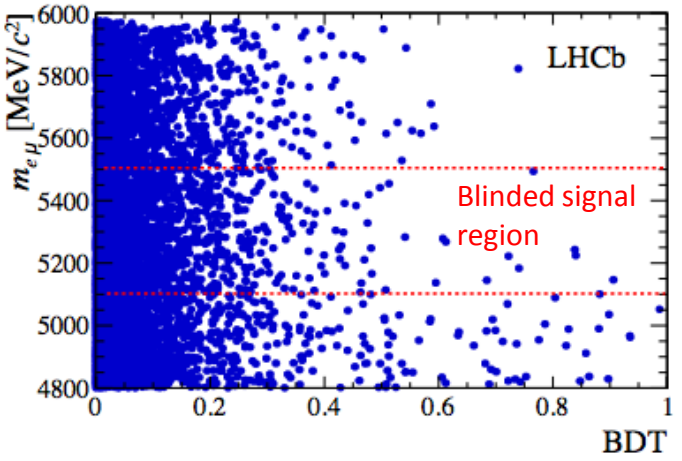
- Previous best branching fraction measurements from CDF [PRL 102, 201801]

  $\mathcal{B}(B_s^0 \to e\mu) < 2.6 \times 10^{-7}$ $\mathcal{B}(B^0 \to e\mu) < 7.9 \times 10^{-8}$ at 95% C.L.

PRL 111, 141801

Analysis Method

- Use 1 fb^{-1} of data collected by LHCb at 7 TeV centre-of-mass energy
- Use normalization channel $B^0 \rightarrow K^+ \pi^-$
- Two-stage multivariate analysis (BDT) – most important discriminating variables: B impact parameter, angle between B momentum and vector joining primary and secondary vertices
- Correct electron momenta for loss due to bremsstrahlung
- Study events in binned 2-D plane:
  - Invariant mass of B candidate
  - Output of second multivariate discriminant (BDT)
- Remaining dominant background eμ pairs originating from different B decays



PRL 111, 141801

Results

- Data consistent with background-only hypothesis
- Set upper limits on branching fractions using CLs method

$\mathcal{B}(B_s^0 \to e\mu) < 1.1(1.4) \times 10^{-8}$

$\mathcal{B}(B^0 \to e\mu) < 2.8(3.7) \times 10^{-9}$ at 90% (95%) C.L.

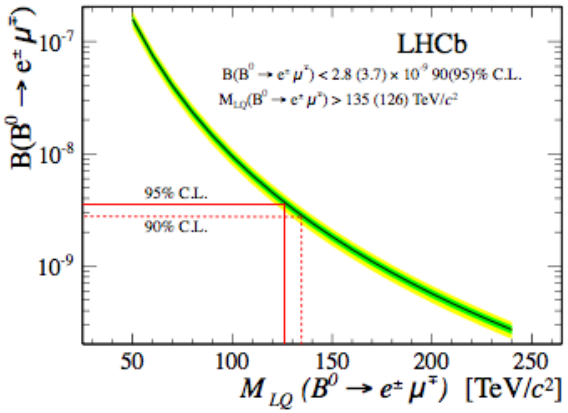
Factor 20 lower than those set previously

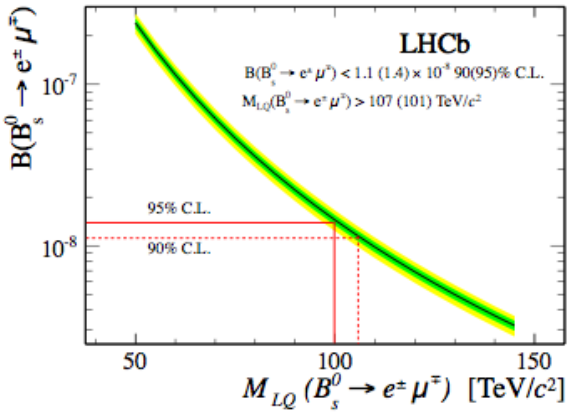
→ lower bounds on masses of Pati-Salam Leptoquarks

$M_{LQ}(B_s^0 \to e\mu) > 101(107)$ TeV/c^2

$M_{LQ}(B^0 \to e\mu) > 135(126)$ TeV/c^2 at 90% (95%) C.L.

Factor 2 higher than those set previously





PRL 111, 141801

Summary

- In absence of signal upper limits set on branching fractions of:
  - Lepton-number violating decay $B^- \rightarrow \pi^+ \mu^- \mu^-$, probing Majorana neutrinos
  - Lepton-flavour violating decays $B_s^0 \rightarrow e\,\mu$ and $B^0 \rightarrow e\,\mu$, leading to lower bounds on masses of Pati-Salam leptoquarks
  - Lepton-flavour violating decay $\tau^- \rightarrow \mu^+ \mu^- \mu^-$, first limit set on this decay at hadron collider

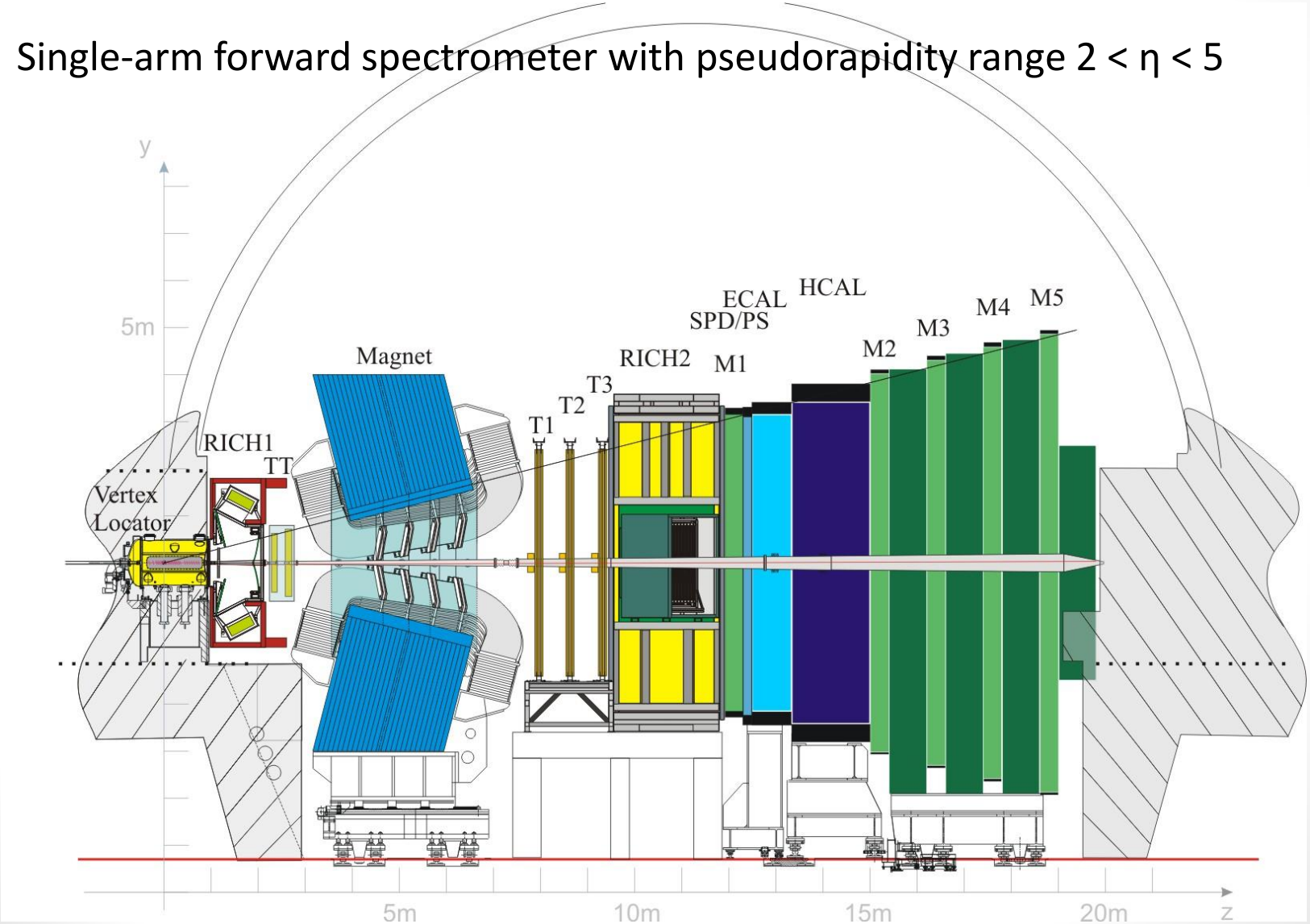
$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 4.0 \times 10^{-9}$ **at 95% C.L.** — Best limit to date

$\mathcal{B}(B_s^0 \rightarrow e^\pm \mu^\pm) < 1.1\ (1.4) \times 10^{-7}$ **at 90% (95%) C.L.**
$\mathcal{B}(B^0 \rightarrow e^\pm \mu^\pm) < 2.8\ (3.7) \times 10^{-8}$ **at 90% (95%) C.L.** — Factor 20 lower than those set previously

$\mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 8.0\ (9.8) \times 10^{-8}$ **at 90% (95%) C.L.** — First at hadron collider

LHCb Detector

Single-arm forward spectrometer with pseudorapidity range $2 < \eta < 5$



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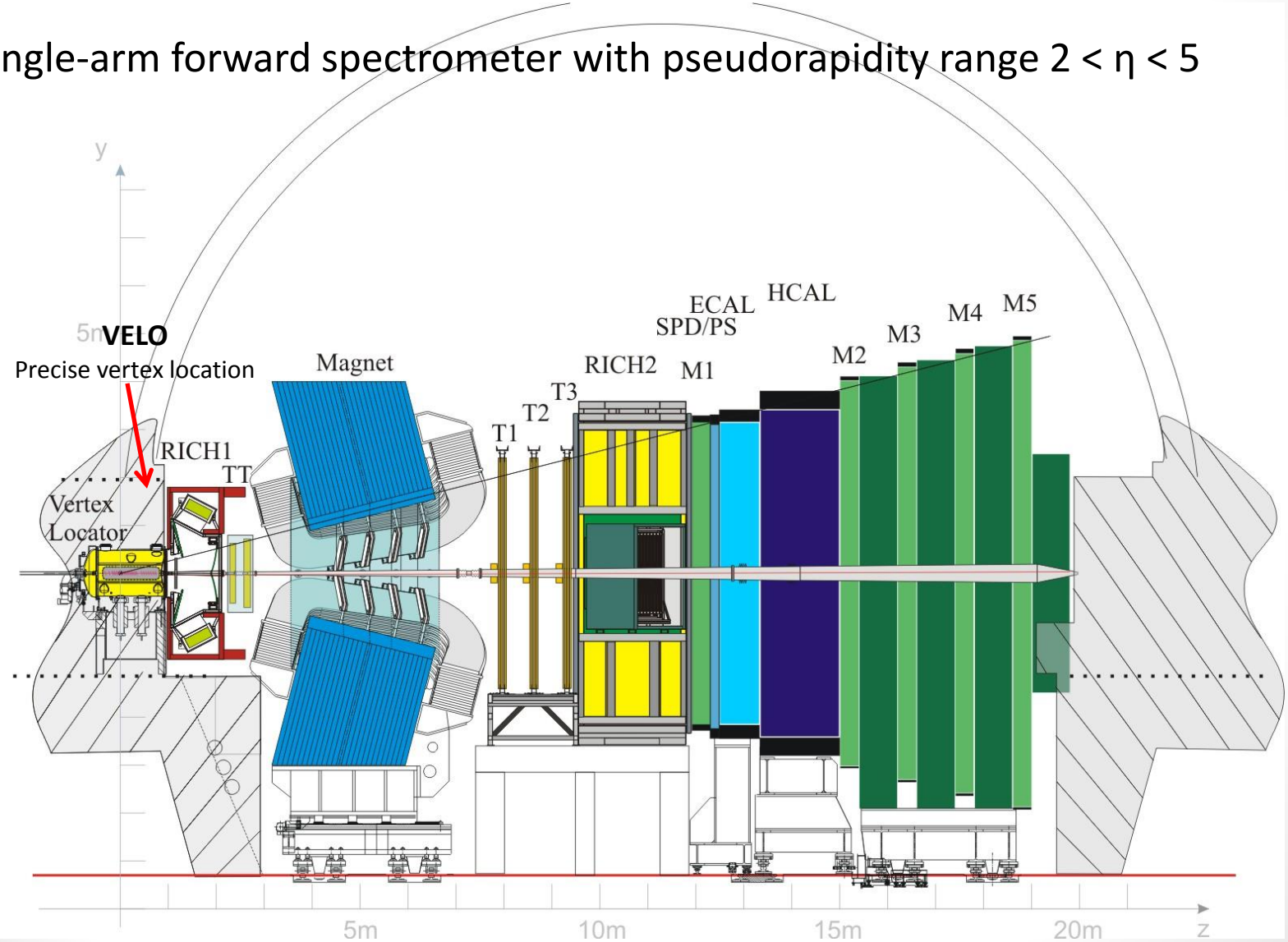

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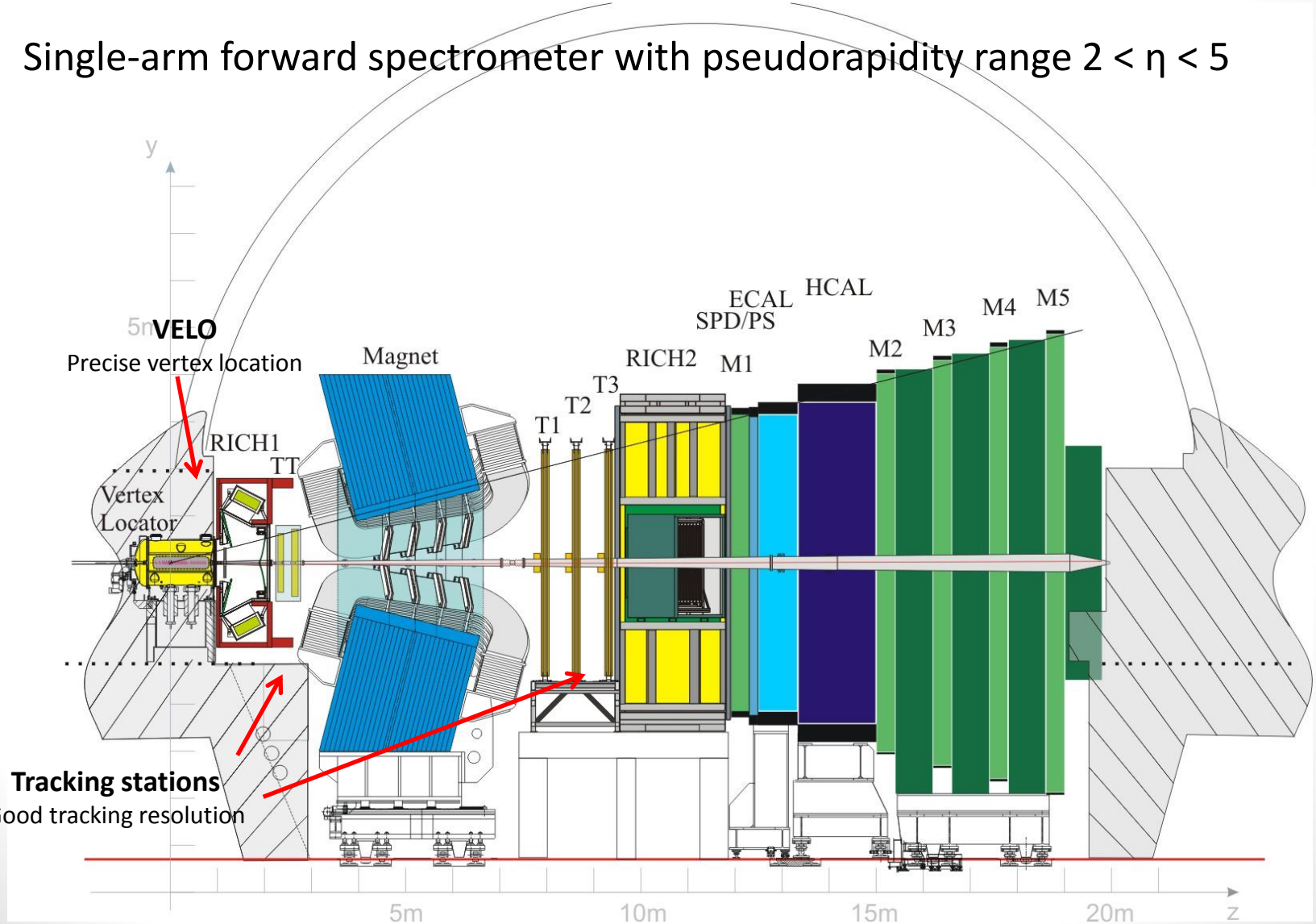

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