XLI PhD cycle
Kick-off presentation

University of Perugia
Department of Physics and Geology

Supervisor:
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Candidate:
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05/12/25

My previous research activities

Bachelor thesis
(University of Perugia, 2023)

Identification of charged kaons with the RICH detector at the NA62 experiment at CERN
- Identify K^+ in the NA62 beam and provide a measurement of their mass

INFN scholarship
(CERN, 2024)

Data/MC comparison for RICH and study of RICH ageing at the NA62 experiment at CERN
- Identify the most likely hypothesis for the origin of hits not associated with a ring and study Data/MC agreement

➡ Co-author of the internal note NA62-25-02

Master thesis
(University of Perugia, 2025)

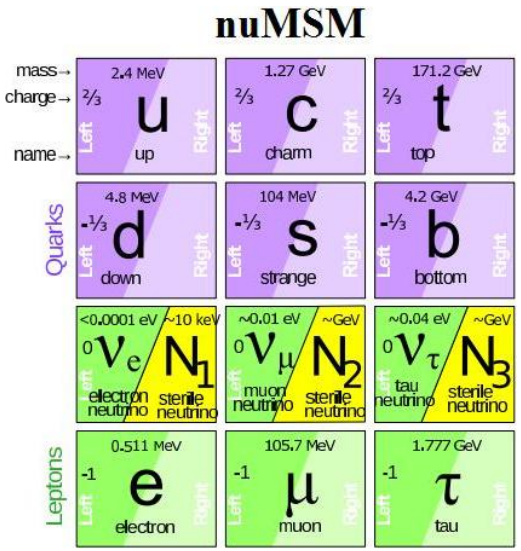
Search for Heavy Neutral Leptons in the B → μ(eπ) decay at the LHCb experiment at CERN
- Event selection, background assessment, expected upper limits for BR(B → $\mu(e\pi)$);

R&D for the LHCb RICH Upgrade II
- Laboratory study of Rayleigh scattering with MCP-PMT

Master thesis

The Standard Model (SM) cannot explain some experimental observations, such as neutrino masses, the baryon asymmetry of the Universe and dark matter

Extension



νMSM (Neutrino Minimal Standard Model) by the addition of HNLs (*N*):
[https://arxiv.org/abs/hep-ph/0503065]

- **Three massive right-handed neutrinos**
- Interaction only via mixing with SM neutrinos $U_\alpha^2 = \sum_I |\Theta_{\alpha I}|^2$ (α = SM flavour, I = HNL flavour)

Heavy neutral leptons have been searched for in a wide range of masses and lifetimes. At LHCb searches in B decays have so far targeted **only** final states with **muons.**

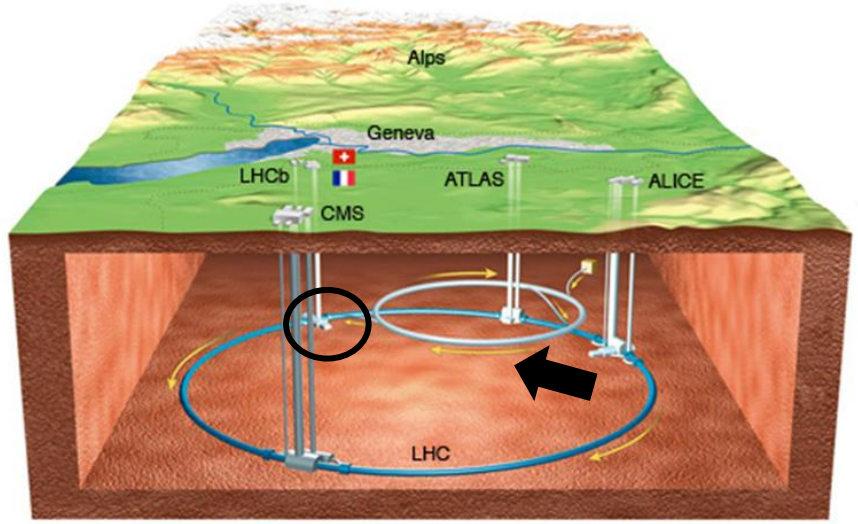
→ This analysis introduces a **new** channel involving electrons: $B^\pm \to \mu^\pm N(\to e^\mp \pi^\pm)$

- Lepton Flavour Violation
- Opposite sign leptons ⟶ HNL can be Dirac or Majorana neutrino

The LHCb experiment

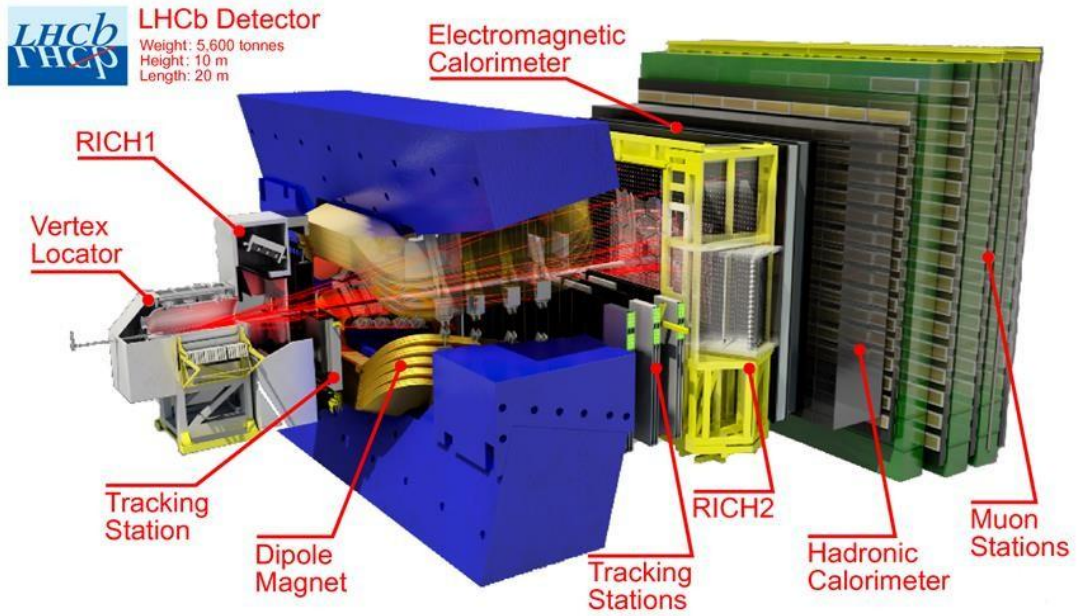
Large Hadron Collider (LHC)

- World largest particle accelerator
- ~ 27 km
- Proton (or heavy ion beams) collide in four interaction points
  - Run 2 (2015–2018) at $\sqrt{s} = 13$ TeV
  - Run 3 started in 2022 at $\sqrt{s} = 13.6$ TeV



Large Hadron Collider beauty (LHCb)

- Single-arm forward spectrometer
- Dedicated to study differences between matter and antimatter

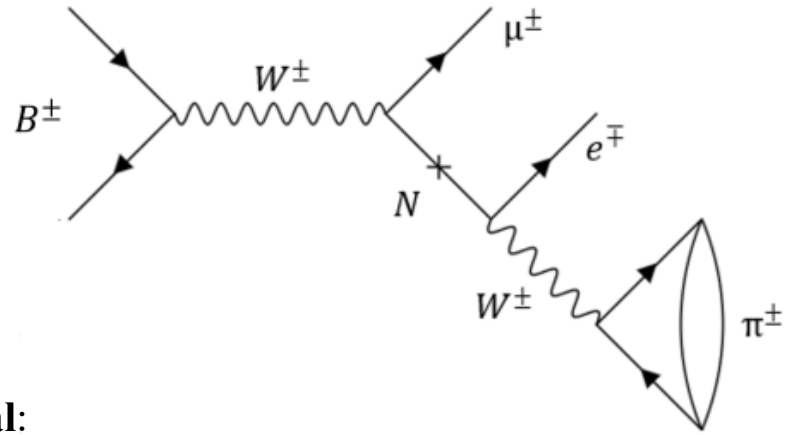


Subdetectors:

- Tracking system
- PID system

Search for Heavy Neutral Leptons in the B → μ(eπ) decay at the LHCb experiment at CERN

$B^{\pm} \to \mu^{\pm} N(\to e^{\mp}\pi^{\pm})$



Goal:
Search for peak in the $m_{e\pi}$ invariant mass spectrum

Normalization channel:
used for the signal BR estimation

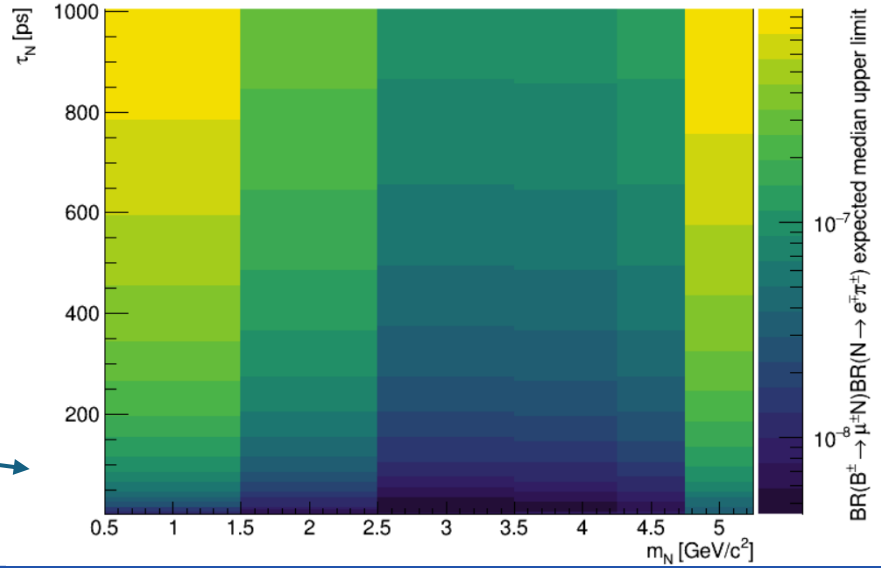
$$\frac{\mathcal{B}(B^{\pm}\to\mu^{\pm}N(\to e^{\mp}\pi^{\pm}))}{\mathcal{B}(B^{\pm}\to K^{\pm}J/\psi(\to\mu^{+}\mu^{-}))} = \frac{N_{\text{events}}(B^{\pm}\to\mu^{\pm}N(\to e^{\mp}\pi^{\pm}))}{N_{\text{events}}(B^{\pm}\to K^{\pm}J/\psi(\to\mu^{+}\mu^{-}))} \cdot \frac{\epsilon(B^{\pm}\to K^{\pm}J/\psi(\to\mu^{+}\mu^{-}))}{\epsilon(B^{\pm}\to\mu^{\pm}N(\to e^{\mp}\pi^{\pm}))}$$

- **Used data**:
  p-p collisions at $\sqrt{s}$= 13 TeV in 2017 (LHCb Run 2), corresponding to 1.7 fb^{-1} of integrated luminosity

- **Test of different signal hypotheses:**
  - $m_N \in [1\ ,\ 5]$ GeV
  - $\tau_N \in [1, 1000]$ ps simulated sample for τ_N = 100 ps, samples with reweighted events for $\tau_N \neq 100$ ps

- **Blind** strategy:
  the signal region in the invariant mass spectrum $m_{\mu e\pi}$ remains hidden

The most stringent limit found:
$\mathbf{4.4 \times 10^{-9}(m_N = 3\ GeV, \tau = 10\ ps)}$



Laboratory study (R&D for LHCb RICH Upgrade II)

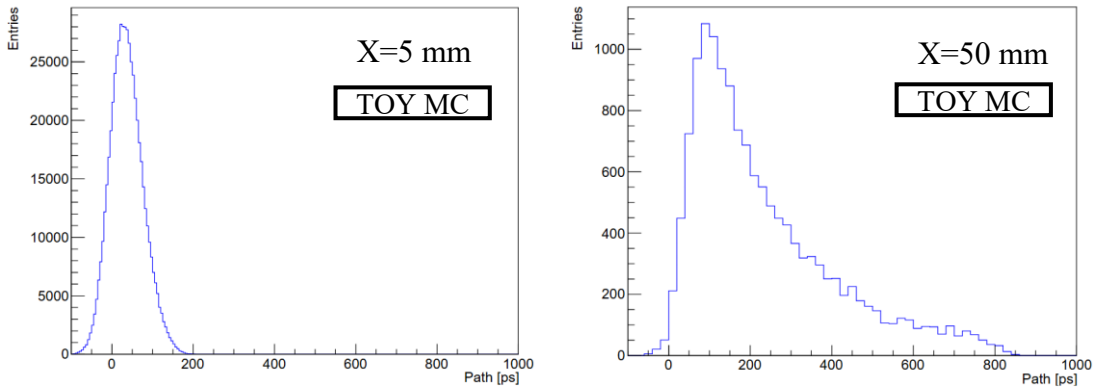
LHCb Upgrade II foreseen during LHC Long Shutdown 4 (LS4, in view of Run 5):

- HL-LHC (Run 5)→ expected to record at least **300 fb^{-1}**
- The RICH system must cope with the high particle flux
- Increased occupancies, harsher radiation environment
- New calibration system based on Rayleigh scattering to better control systematic effects

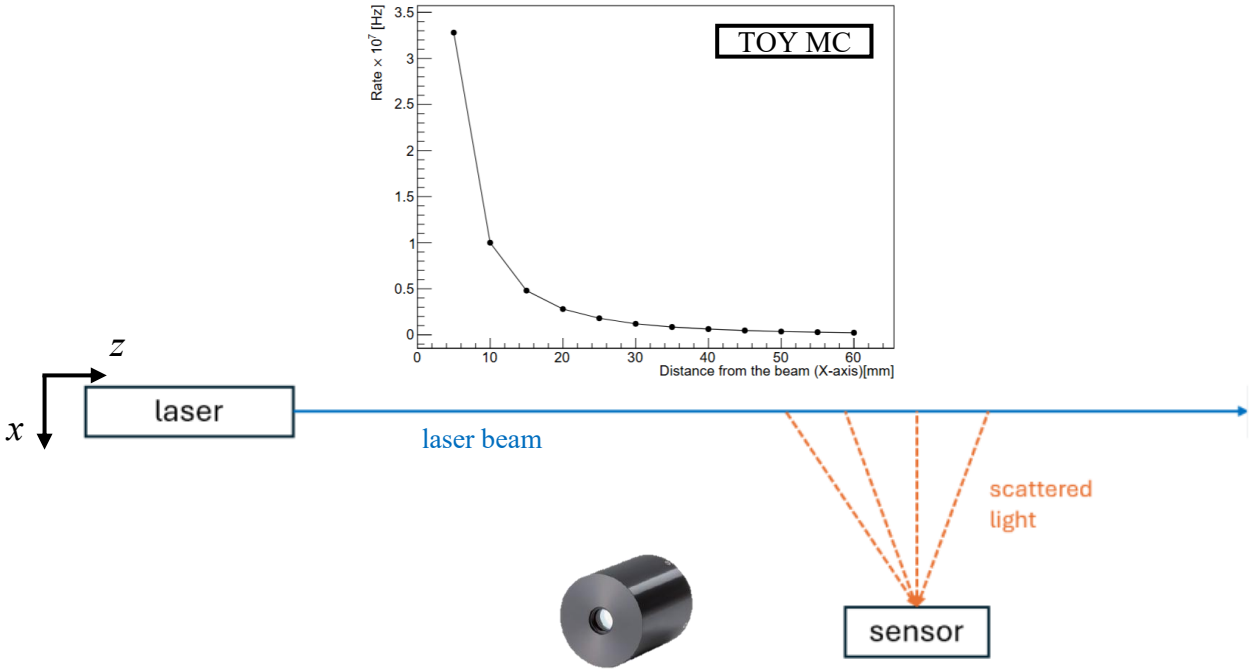
- Laboratory measurements (@ LHCb Perugia Lab)+ Toy MC simulations
- Detect Rayleigh-scattered photons using MCP-PMT
- Findings:
  - ✓ Photon rate decreases, time distribution broadens with sensor–beam distance
  - ✓ To keep ~100 ps resolution, transverse distance < 45 mm

- **Rate measured**:
  - $R_{\text{Rayleigh}} = 6.7\text{Hz}$
  - Emitted light from laser $R_{\text{beam}} = 1.7 \times 10^{8}$ Hz
  - Ratio: 4.0×10^{-8}

Time-of-arrival distribution



Intensity distribution



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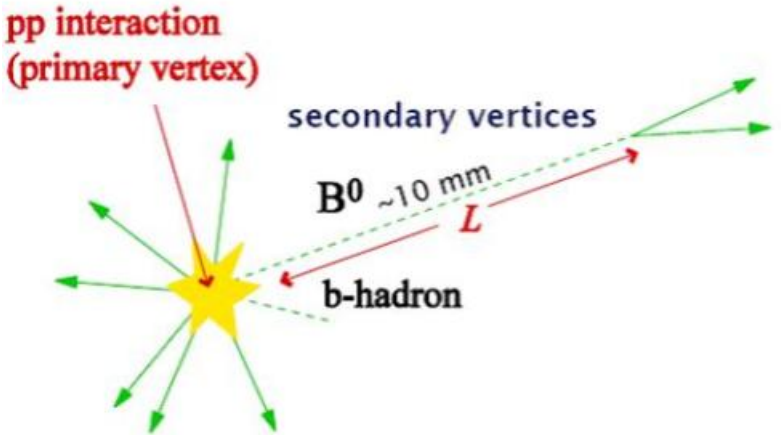
Training plan & research activities

- International workshops, schools, conferences etc. related to the PhD project throughout the 3 years
- PhD courses in the 1st year

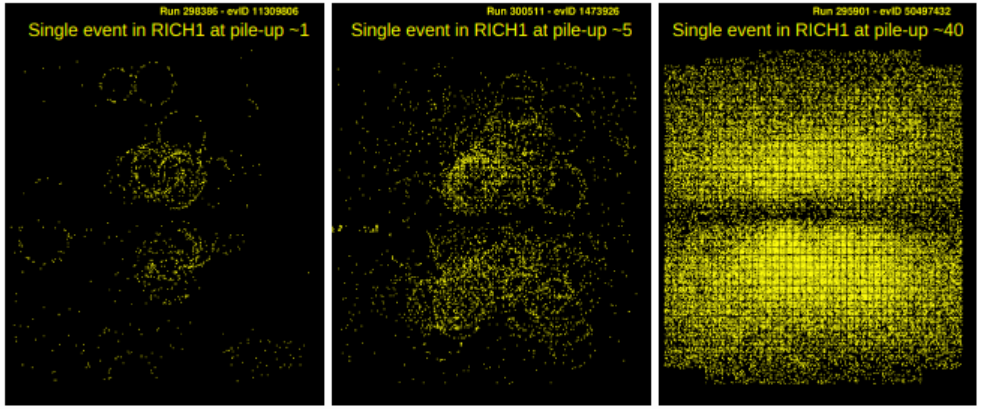
⟶ (see Backup slide)



1 Study of rare and forbidden B meson decays at LHCb

Powerful probes of physics Beyond the Standard Model:

- Search for new particles (e.g. Heavy Neutral Leptons, …)
- Search for Lepton Number/Flavour Violation



2 R&D activities for future upgrades of the LHCb RICH detectors

- Next-generation photon detectors & calibration and monitoring tool

⟶Improve or at least maintain the PID performance of Run 3 but in much harsher conditions

Thank you for your attention!

Backup slides

My Doctoral Study Plan

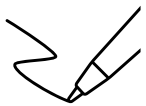
EDUCATION ACTIVITIES @ PhD Physics course (minimum 12 ECTS)	**YEAR (I, II, or III)**	**N. Hours**	**N. ECTS**
List of courses, seminars, etc. specifically activated for the PhD course			
Physics at Collider	I	9	1.5
Flavour Physics	I	9	1.5
Future Experiments	I	6	1
Detectors for ionizing radiations	I	6	1
Introduction to Quantum Computing	I	18	3
Teaching and Learning Physics	I	21	3.5
Machine Learning and Deep Learning for Physics	I	12	2
Advanced Topics in Astroparticle Physics	I	15	2.5
Nanosystems	I	18	3

EDUCATION ACTIVITIES @ other PhD Courses	**YEAR (I, II, or III)**	**N. Hours**	**N. ECTS**
List of courses, seminars, etc. specifically activated for the PhD course			
Seminaries PerAPS-2026 Cycle	I		

Frontal and cross-disciplinary teaching at the University and/or another Doctoral Program, possibly from another University, with a multi/inter/trans-disciplinary approach (Minimum 6 ETCS)	**YEAR (I, II, or III)**	**N. Hours**	**N. ECTS**
Etica della ricerca (Dipartimento di Ingegneria)	I	12	2

Other education activities (E.g. conference, doctoral schools, seminars etc)	**YEAR (I, II, or III)**	**N. Hours/days**	**N. ECTS**
N. of conferences			
N. of seminars			
N. doctoral schools			
...			
LHCb Starterkit 2025	I	5d	5
118th LHCb week	I	5d	5
INFN School of Statistics 2026	I	5d	5

Other training activities (E.g. teaching, tutoring, outreach etc). These activities do not provide ECTS	**YEAR (I, II, or III)**	**N. Hours/days**	
Hands On Physics Project	I	2d	
Member of the Scientific Committee for the Asimov Prize	I	2025-2026	
LHCb Masterclass 2026	I	1d	



The study plan is indicative and may evolve as the PhD progresses (e.g. course choices or additional activities).