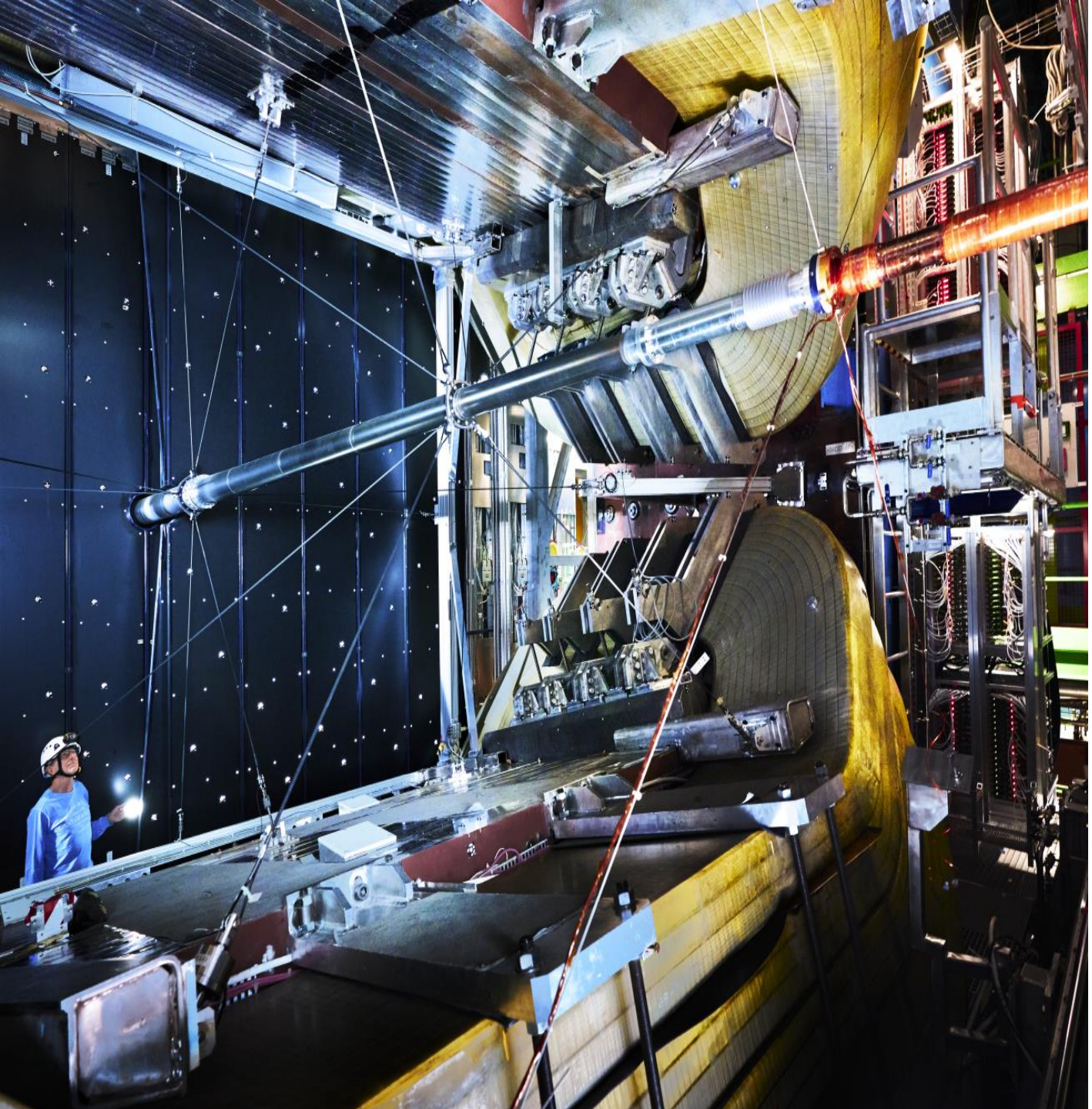


First year of PhD report

Lisa Fantini, XXXVII cycle of the PhD in Physics

Supervisors: Giuseppina Anzivino, Viacheslav Duk

28th October 2022

Outline

- Research activity: LHCb experiment
  - Search for Heavy Neutral Leptons in B meson decays
  - Light Leak Detector
  - RICH Upgrade test beam

Data analysis

Detector work

- Additional activities:
  - Courses
  - Others…

LHCb experiment at LHC

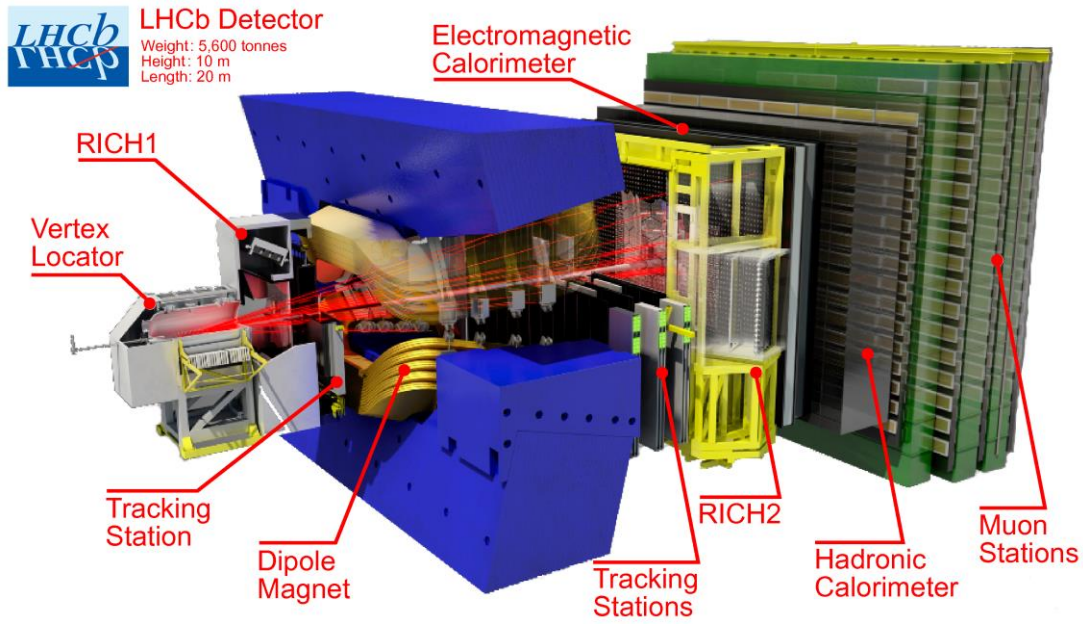
Large Hadron Collider (LHC):

- the highest energy accelerator in the world
- proton-proton collisions

Large Hadron Collider beauty (LHCb):

- one of the four big LHC experiments
- Forward spectrometer of ~20m
- Different subdetectors for:
  - tracking
  - identification
  - measuring energy/momentum

  of particles



Physics at LHCb

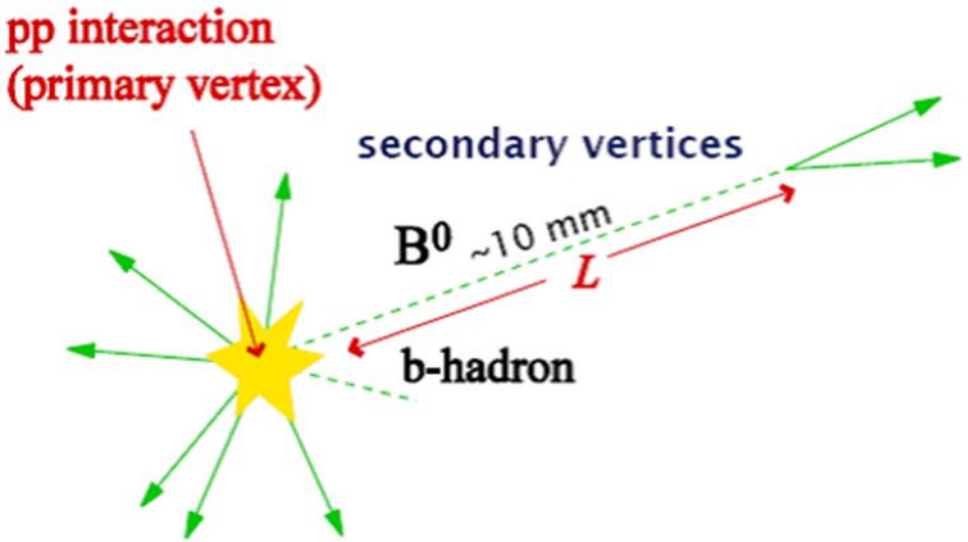
b is for beauty

LHCb is dedicated to the physics of beauty quark:

- differences between matter and antimatter (Baryon asymmetry of the Universe)
- B meson rare decays (sensitive to physics beyond Standard Model)
- beyond the baseline: rare decays of D, Σ, Λ, K...

B mesons:

- absent in the Universe today (→ unstable)
- abundant immediately after Big Bang

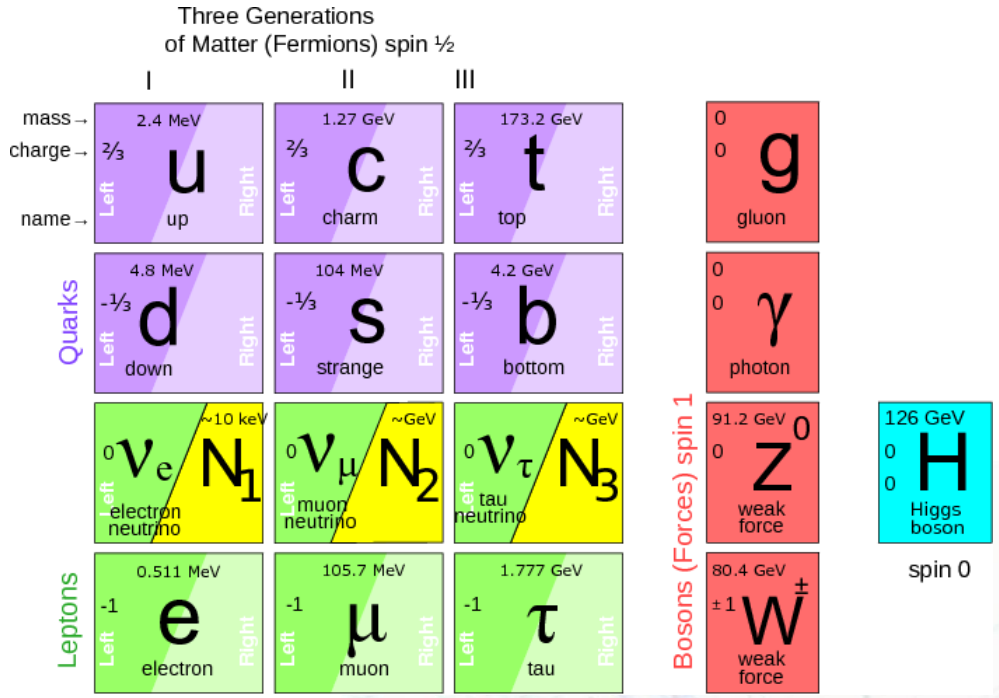


HNLs: an introduction

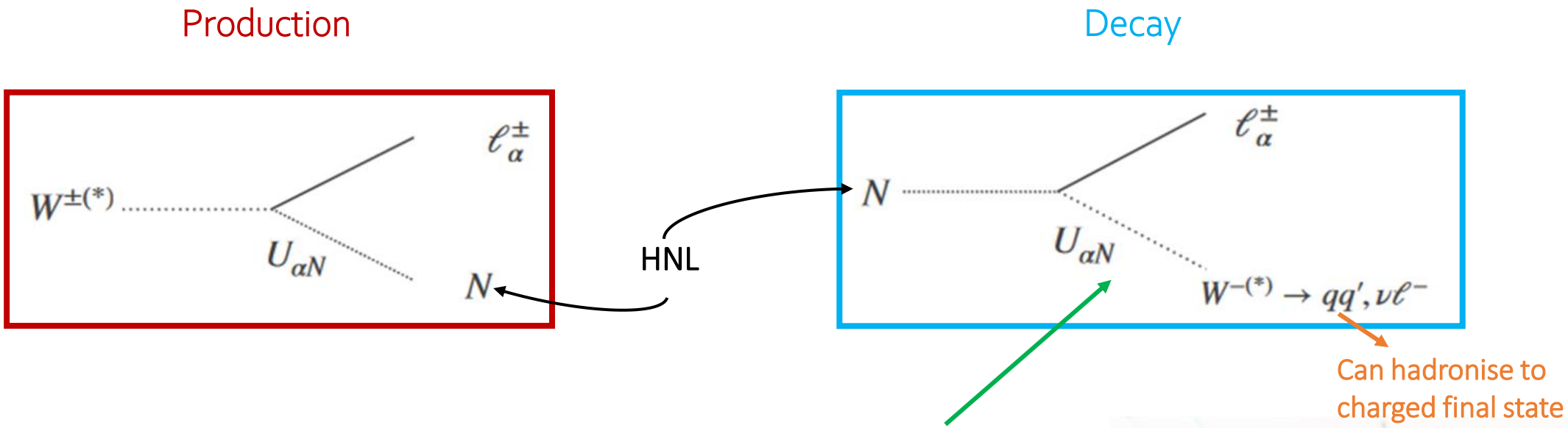
- Some experimental observations cannot be explained by Standard Model (SM) without a minimal extension:
  1. Neutrino oscillations
  2. Baryon asymmetry of Universe
  3. Dark matter

→ extension to the νMSM (neutrino Minimal Standard Model) by addition of **Heavy Neutral Leptons (HNLs):** [arXiv:hep-ph/05030]

- massive right-handed neutrinos
- singlets under SM gauge
  → only interaction via mixing with the SM neutrinos



HNLs: production and decay



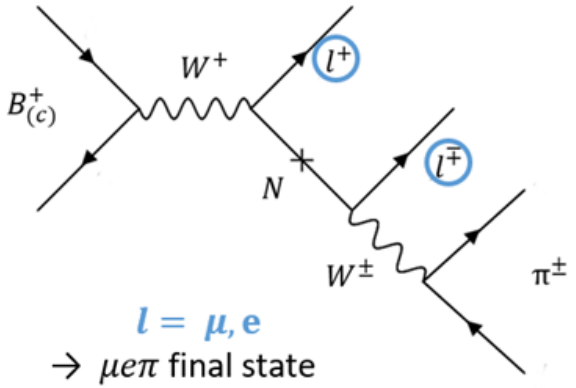
- Could be detected by the decay into two charged particles
- $U_{\alpha N}$ parameters: HNL mixing with SM neutrino (α = flavour)
- Signal rate proportional to $U_{\alpha N}^{prod} U_{\alpha N}^{dec}$

HNLs: state of the art

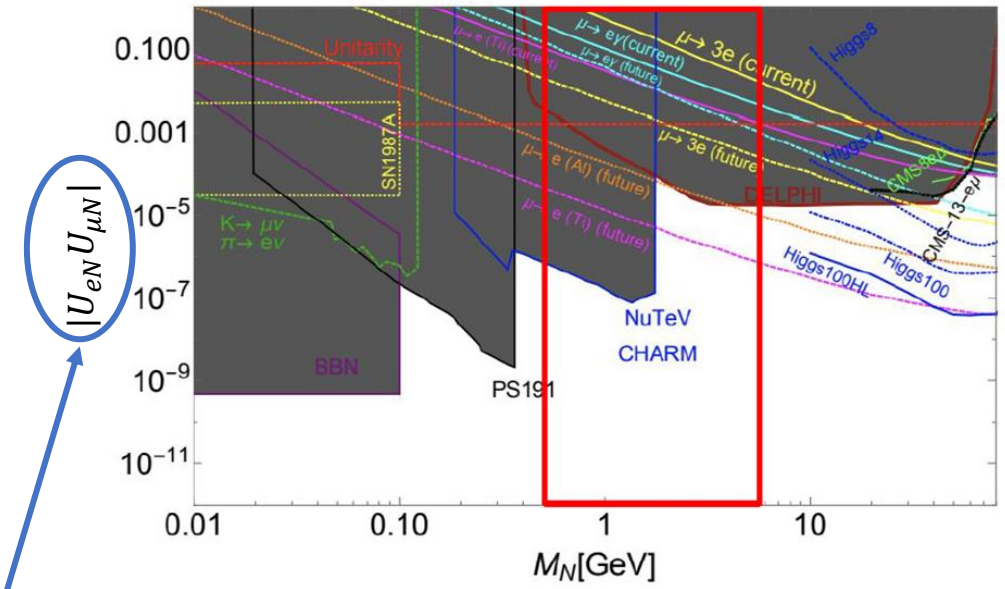
Main HNLs (N) searches from B meson decays

- Belle experiment:
  - $B \to XlN(\to l\pi)$ with $l = \mu, e$, limits on $U^2_{\mu N}$ and U^2_{eN} [arXiv: 1301.1105]

- LHCb experiment:
  - $B \to \mu N(\to \mu\pi)$ limit on $U^2_{\mu N}$ (Run 1 data) [arXiv:1401.5361v2]
  - $B \to X\mu N(\to \mu\pi)$ ongoing (Run 2 data)



Current limits on light-heavy neutrino mixing angles



Range of mass that B decays can explore:
[0.5 GeV - m_B]

Our analysis:

Opportunity to probe mixing with electrons and set new limit on $U_{eN}U_{\mu N}$

Analysis strategy: aim

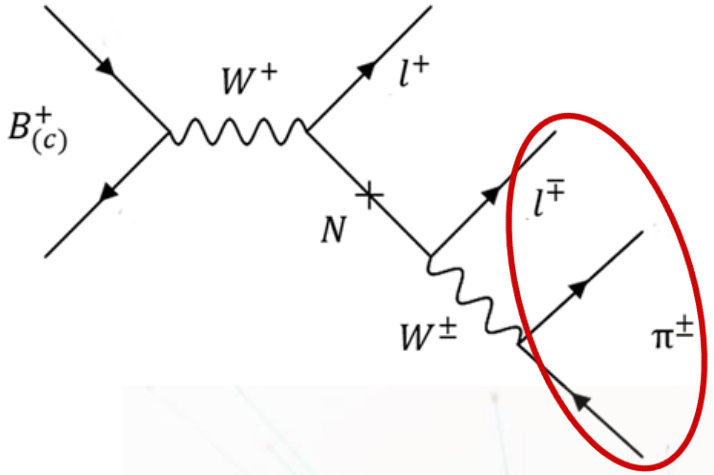
- search for Heavy Neutral Leptons (N) in $\boldsymbol{B^+}$ and $\boldsymbol{B_c^+}$ decays

- quest for a bump in the $m_{\pi l}$ invariant mass spectrum

  - testing different hypotheses of neutrino mass (m_N) and lifetime (τ_N):
    - $m_N \in [0.5\ ,5\ (6)]GeV$
    - $\tau_N \in [0, 1000]ps$

  - both prompt and displaced reconstruction categories

  - **Run 2 data** (2016-2018)



Analysis strategy: signal channels

HNLs can be Dirac or Majorana neutrinos

$N \neq \bar{N}$ $\qquad$ $N = \bar{N}$

Two different lepton signatures:

1) Opposite Sign (OS) leptons:

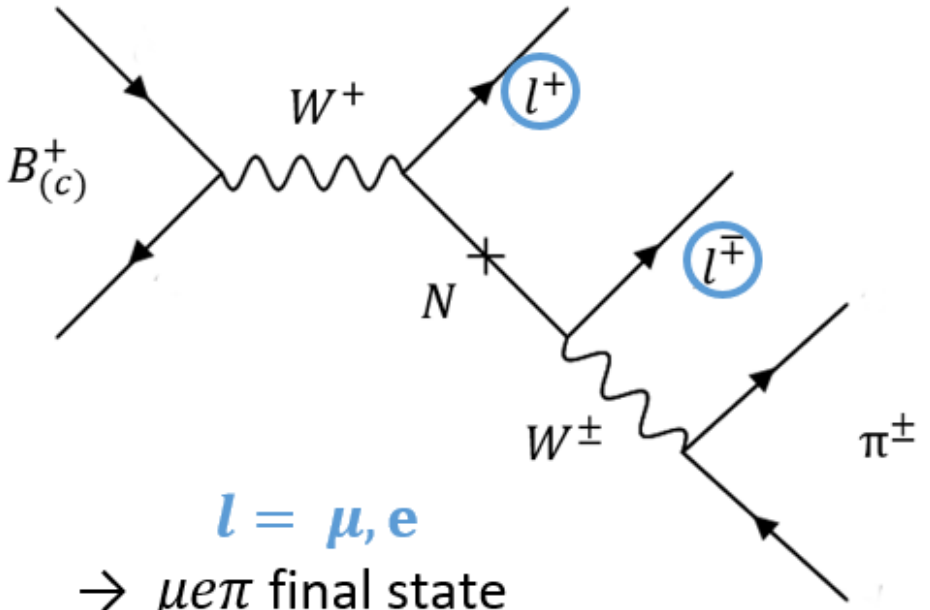
$B^+_{(c)} \to \mu^+ N(\to e^- \pi^+) \quad B^+_{(c)} \to e^+ N(\to \mu^- \pi^+)$

→ Majorana and Dirac neutrino
Lepton Flavour Violation

2) Same Sign (SS) leptons:

$B^+_{(c)} \to \mu^+ N(\to e^+ \pi^-) \quad B^+_{(c)} \to e^+ N(\to \mu^+ \pi^-)$

→ only Majorana neutrino
Lepton Flavour Violation and Lepton Number Violation



$l = \mu, e$

→ $\mu e \pi$ final state

Analysis strategy: normalization channels

Number of signal events: .

difficult to evaluate

$$N_{sig} = N_{B\ in\ data}\, BR(B \to lN) BR(N \to l\pi)\, \varepsilon_{sig}$$

→ solution: **normalization to a well known process**

$$N_{sig} = N_{norm} \frac{BR(B \to lN)\, BR(N \to l\pi)\, \varepsilon_{sig}}{BR(norm\ process)\, \varepsilon_{norm}}$$

In my analysis: possible normalization channels

$$B^+ \to K^+ J/\psi(\to \mu\mu) \qquad B^+ \to K^+ J/\psi(\to ee)$$

$$B^+ \to \pi^+ K_s^0(\to \pi\pi)$$

Current status of the analysis

- Produced signal MC samples (2017) for one mass point and two lifetime points
  $m_N = 3\ GeV \qquad \tau_N = 0\ ps, 20\ ps$
- Produced MC samples for the first normalization channel: $B^+ \to K^+ J/\psi(\to \mu\mu)$ (2017)
- Root files with variables for data are ready
- Developed strategy to simulate the many mass and lifetime points of signal
- Ongoing studies on normalization
- Ongoing studies on cut-based signal selection
  → particular attention to PID variables

Next steps

- Development of a MVA signal selection (expected higher efficiency with respect to cut-based one)
- First signal efficiency studies
- Production of signal MC samples with larger lifetime (displaced selection)
- Continue the study of normalization channels

Light Leak Detector

- Perugia group is part of the LHCb team that deals with **RICH (Ring-imaging Cherenkov) detectors**
  → crucial for particle identification

- I have worked on **Light Leak Detector (LLD)**→
  - subsystem for detection the optic photons from outside the experimental setup
  - made of Photo Multiplier Tubes (PMTs) (6 for RICH1 and 6 for RICH2)
  - gives an alarm when the rate of optical photons in the RICH chamber exceeds a specified threshold
  - monitoring of luminosity at interaction point

- LLD designed and built entirely by the LHCb Perugia group

- My contribution:
  - calibration
  - testing of readout electronics
  - data analysis during commissioning

- Now: LLD is installed at CERN and integrated in the RICH control system

RICH Upgrade test beam (October 2022)

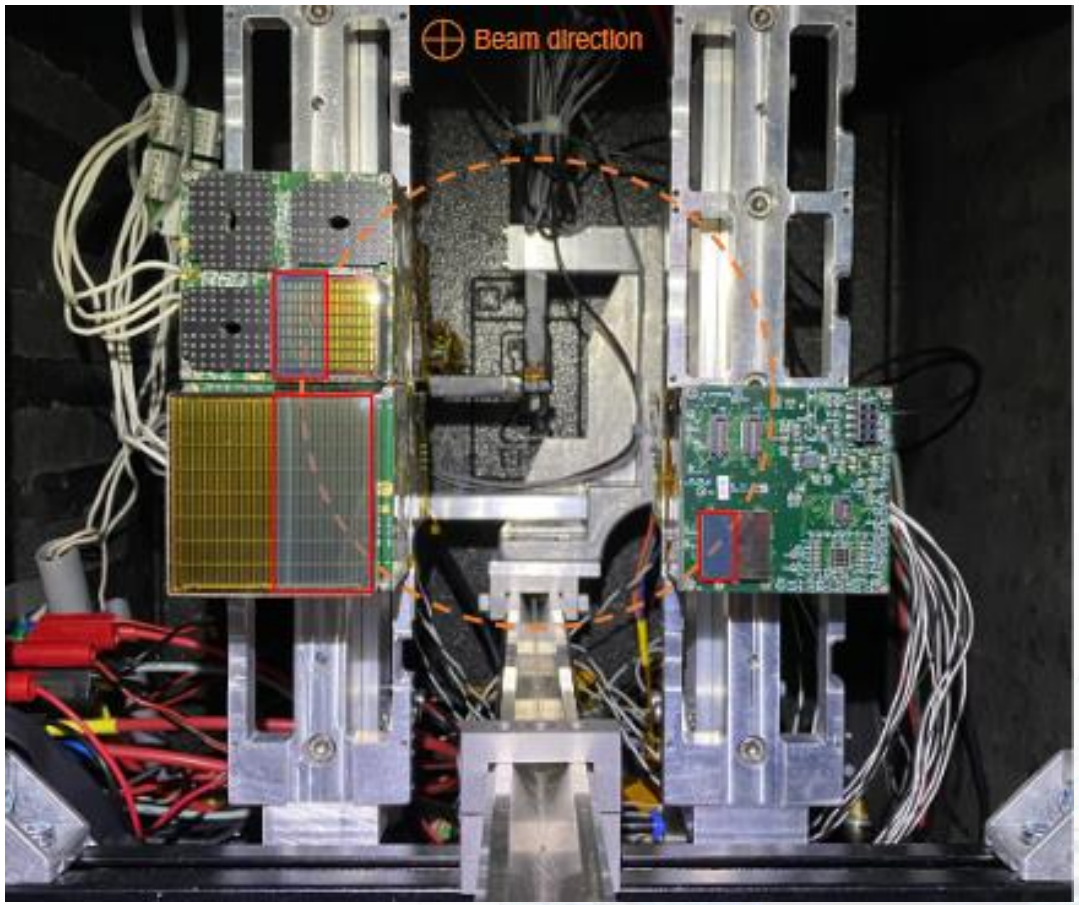
- LHC Run 3 is just started (2022)

- R&D for Run 4 (2029) and Run 5 (2035) ongoing
  → **higher luminosity (HL-LHC), RICH upgrade needed**

- October 2022 test beam:
  - test of faster electronic for MAPMT (RICH photon sensors) readout → FastIC
  - measurement of FastIC time resolution

- My contribution:
  - optimization of MCP (external trigger) time resolution
  - data taking

Experimental setup



Courses attended

✓ with exam/laboratory

- Effective Field Theory
  - Theory (Buttazzo) ✓
  - Spintronic (Tatara)
- Uncertainty and Probability (D'Agostini) ✓
- Nanosystems
  - Molecular nanomagnets for quantum computation (Garlatti/Chiesa)
  - Raman spectroscopy (Ripanti)
  - Spectroscopy characterization of nanostructured material (Pedio)
- Physics at Colliders (Gallinaro)
- Introduction to space physics (Tommasetti)
- Flavour physics (Ruggiero) ✓
- Multimessenger
  - Gamma Rays (Tosti)
  - Neutrinos (Germani)
  - Gravitational waves (Punturo)
- Teaching and learning physics (Organtini) ✓

Additional activities

Meetings:
- LHCb Italia (LNF)
- LHCb week (Dortmund)

Talks:
- Rare Decays WG

Papers:
- "Search for exotic hadrons with the CMS experiment"
  Il Nuovo Cimento 45 C (2022) 106
  DOI 10.1393/ncc/i2022-22106-8

Schools:
- INFN School of Statistics (Paestum)

Activities at LHCb:
- Data Manager shifts in LHCb Control Room
- RICH piquet shift (next November)

Thanks for the attention!