The LHCb Experiment

Marco Pappagallo

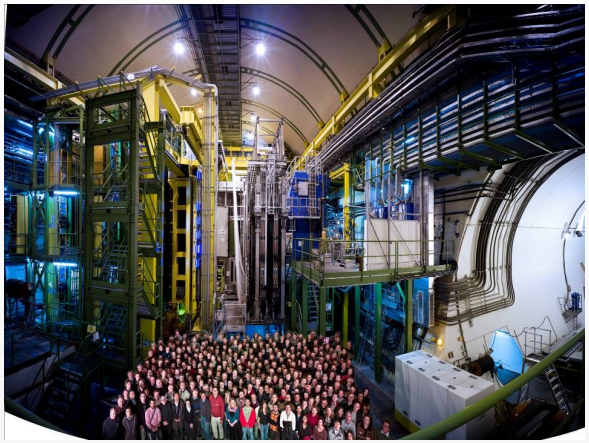
On behalf of the LHCb Bari group

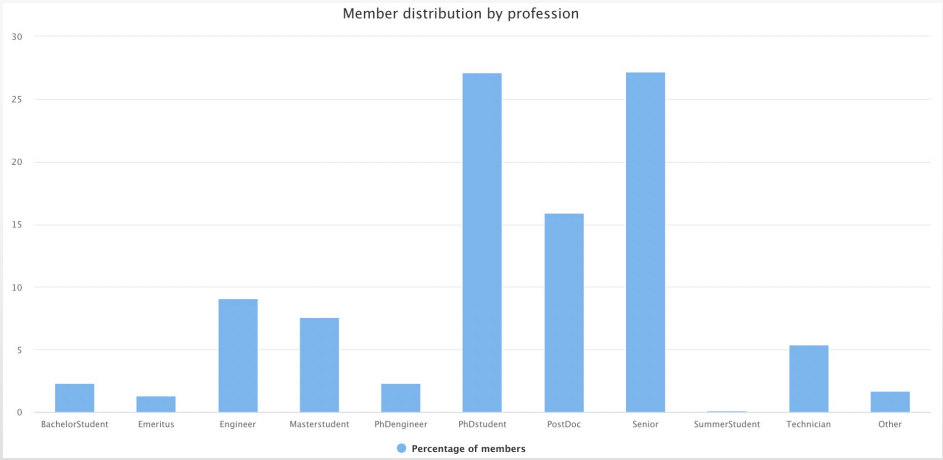
INFN and University of Bari

LHC Fest
12-13 October 2023

THE LHCb COLLABORATION

- **1610** members from **96** institutes in **21** territories
  - **1066** authors signing physics papers now
  - **341** authors signing the exp. proposal in 1998, **690** the upgrade proposal in 2012





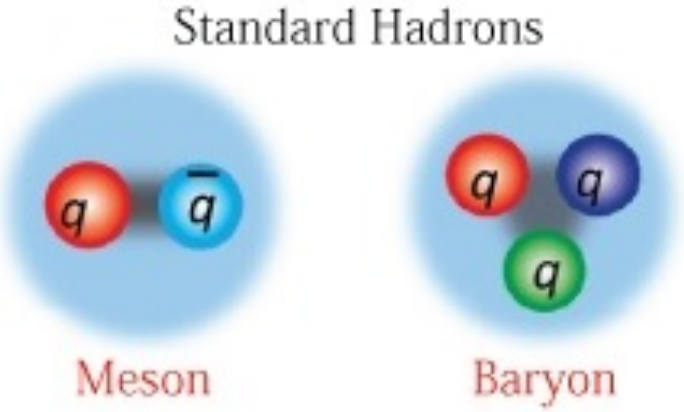
Expanding collaboration with many opportunities across physics, operations and detector and software development.

LHCb @ Bari

- Prof. Simone Saverio
- Prof. De Serio Marilisa
- Prof. Pappagallo Marco
- Dr Pastore Alessandra (INFN)
- Dr Fini Rosa Anna (INFN)
- Dr Galati Giuliana (Post-doc)
- Dr D'Argent Philippe (Post-doc)
- Debernardis Francesco (PhD)

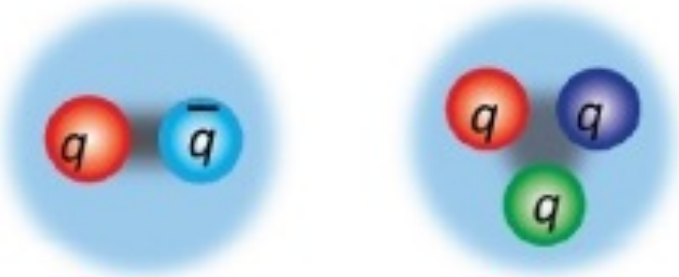
Hadron Spectroscopy

Structure of Hadrons

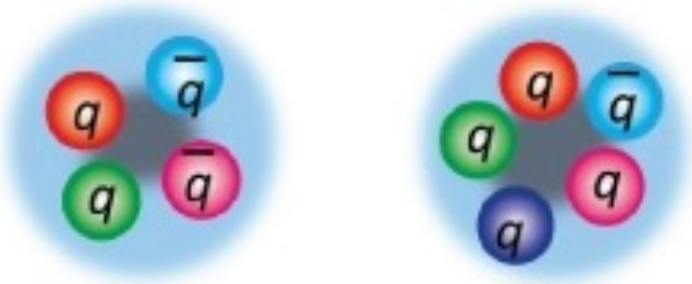


Structure of Hadrons

Standard Hadrons

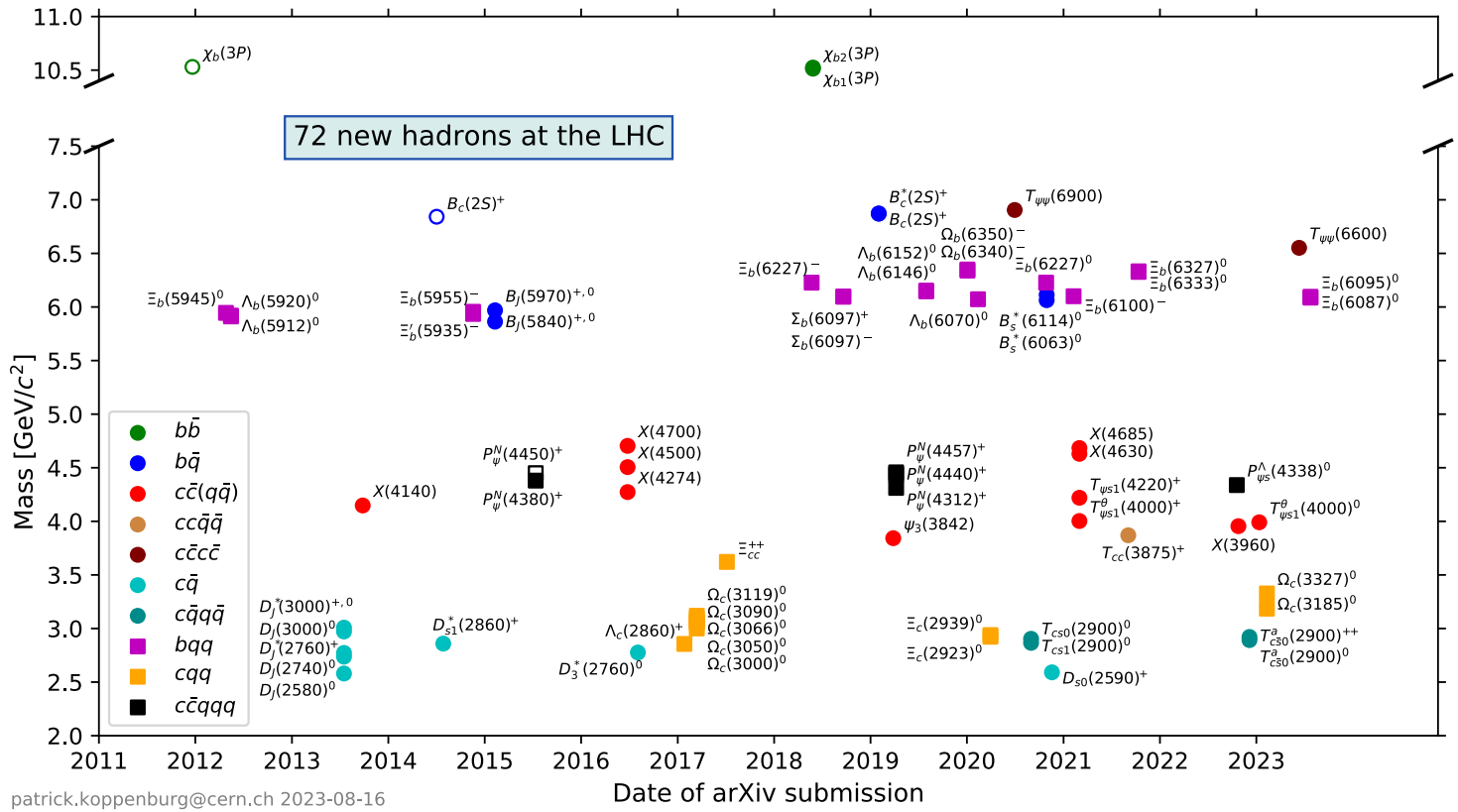


Exotic Hadrons



70+ New Hadrons at LHC!

The LHC experiments have discovered 72 new hadrons:
ATLAS (3), CMS (5), LHCb (64)



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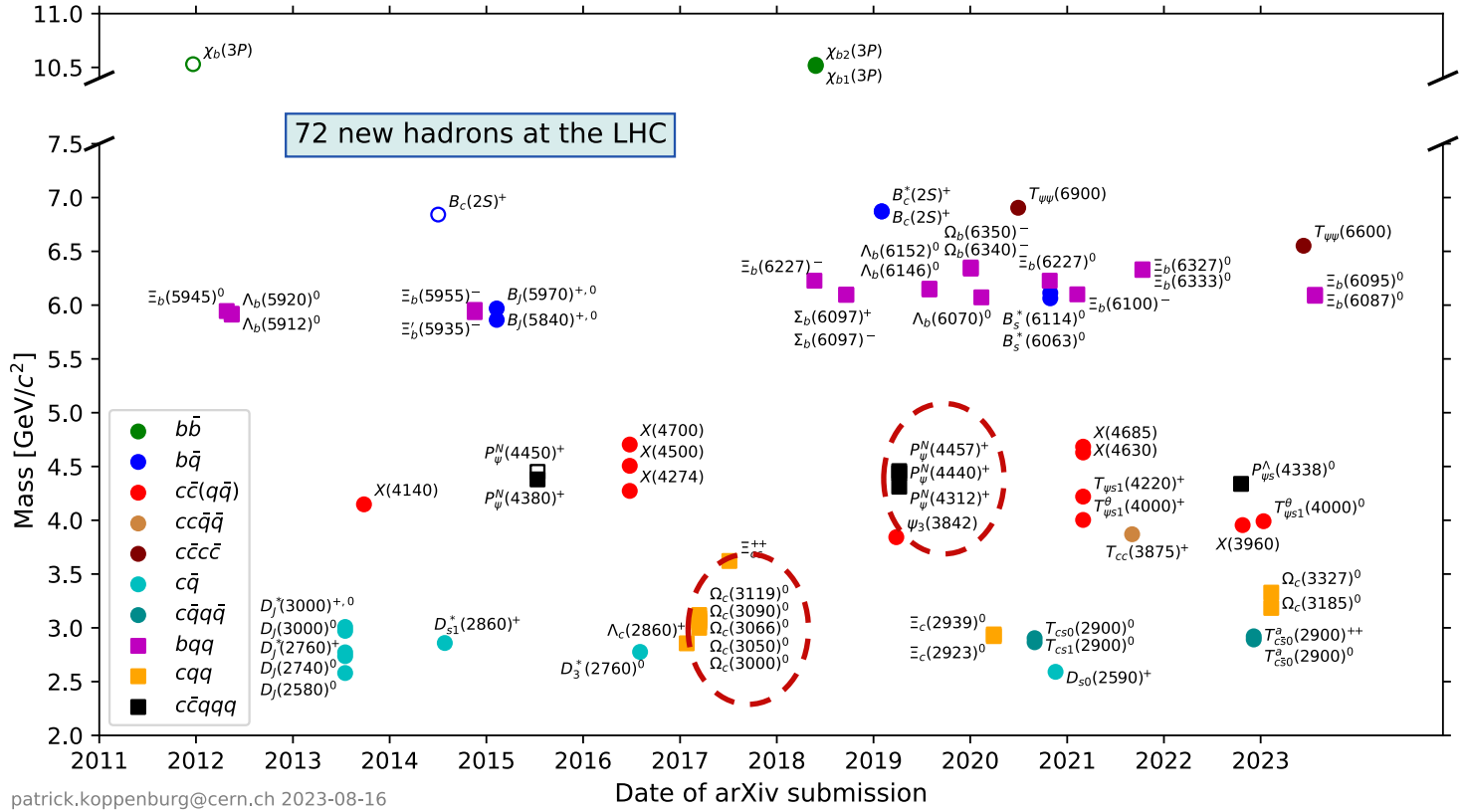
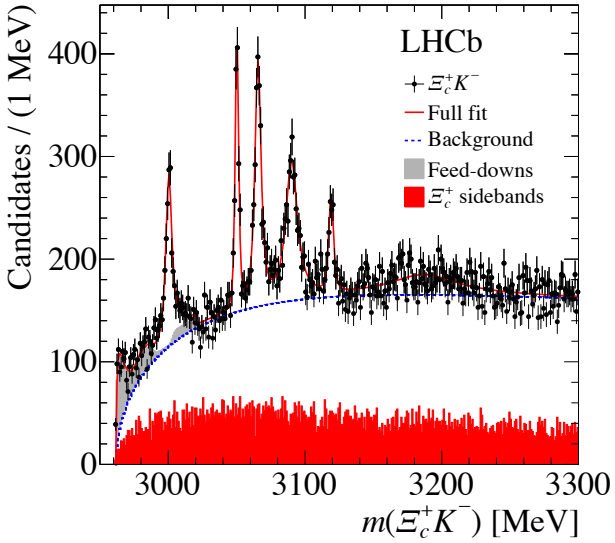
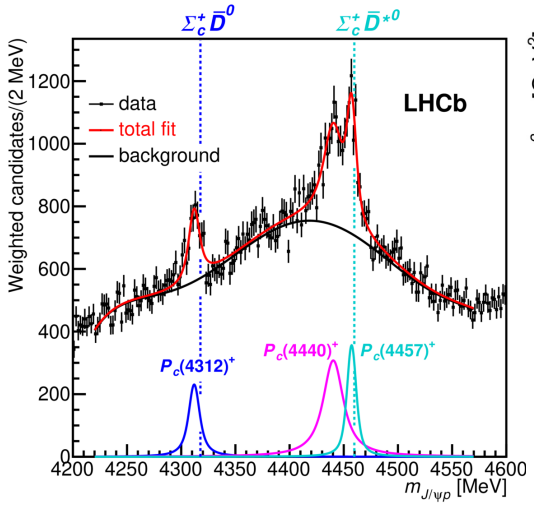


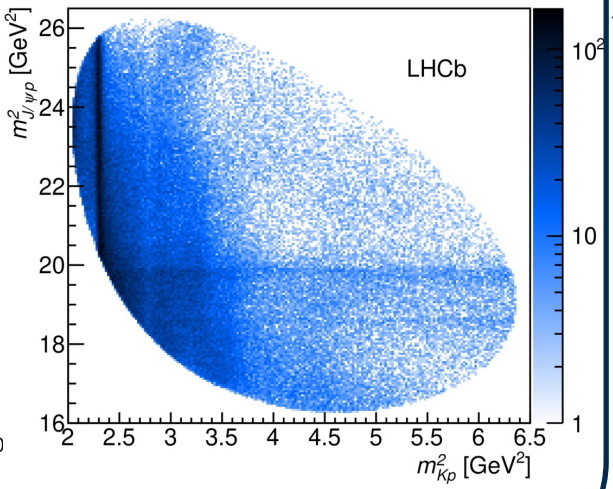
New Hadrons at LHCb

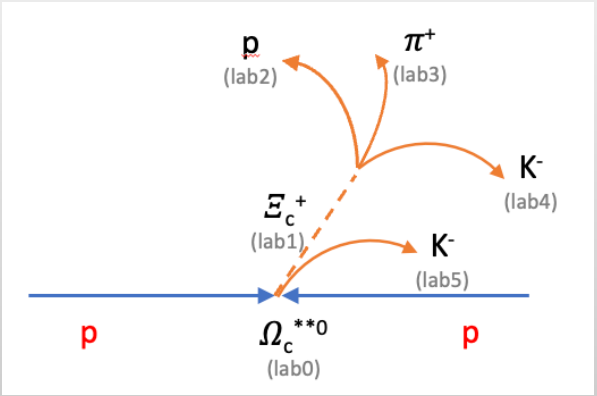
http://arxiv.org/abs/1703.04639

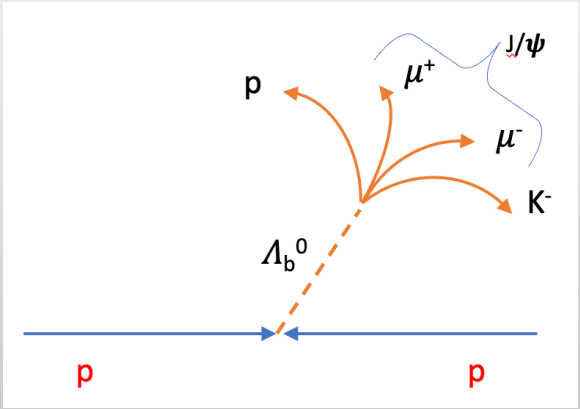


http://arxiv.org/abs/1904.03947



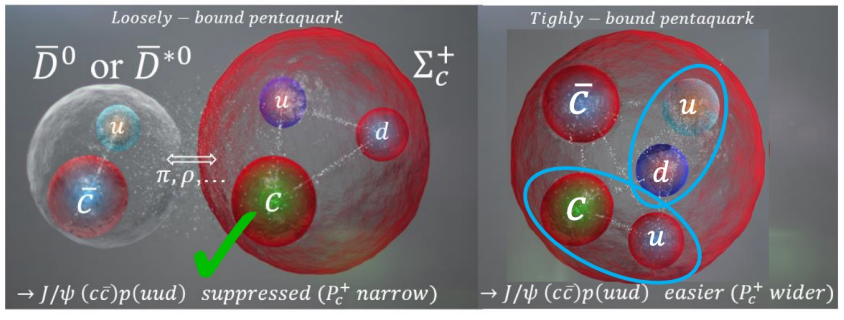


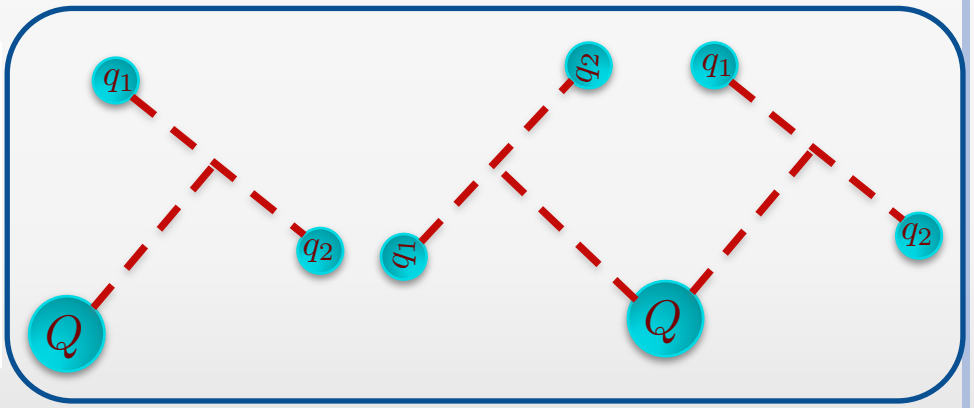




The Relevance of Spectroscopy

- The discovery of new particles provides provide insight into a still-to-be-fully-understood corner of the SM, namely confinement. How are the hadrons bound? Is the diquark a building block for hadrons?





- Understanding strong interactions could be important for new high energy phenomena
  - ✓ Higgs boson as a composite state
  - ✓ Strong interactions in a dark sector (arXiv:1602.00714)
  - ✓ Hadronic dark matter?

Spectroscopy is a Hot Topic

Discoveries in spectroscopy are between the most cited papers

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays #1

LHCb Collaboration · Roel Aaij (CERN) et al. (Jul 13, 2015)

Published in: *Phys.Rev.Lett.* 115 (2015) 072001 · e-Print: 1507.03414 [hep-ex]

pdf · links · DOI · cite · claim · reference search · 1,620 citations

Test of lepton universality using $B^+ \to K^+ \ell^+ \ell^-$ decays #2

LHCb Collaboration · Roel Aaij (NIKHEF, Amsterdam) et al. (Jun 25, 2014)

Published in: *Phys.Rev.Lett.* 113 (2014) 151601 · e-Print: 1406.6482 [hep-ex]

pdf · DOI · cite · claim · reference search · 1,319 citations

Test of lepton universality with $B^0 \to K^{*0} \ell^+ \ell^-$ decays #3

LHCb Collaboration · R. Aaij (CERN) et al. (May 16, 2017)

Published in: *JHEP* 08 (2017) 055 · e-Print: 1705.05802 [hep-ex]

pdf · links · DOI · cite · datasets · claim · reference search · 1,273 citations

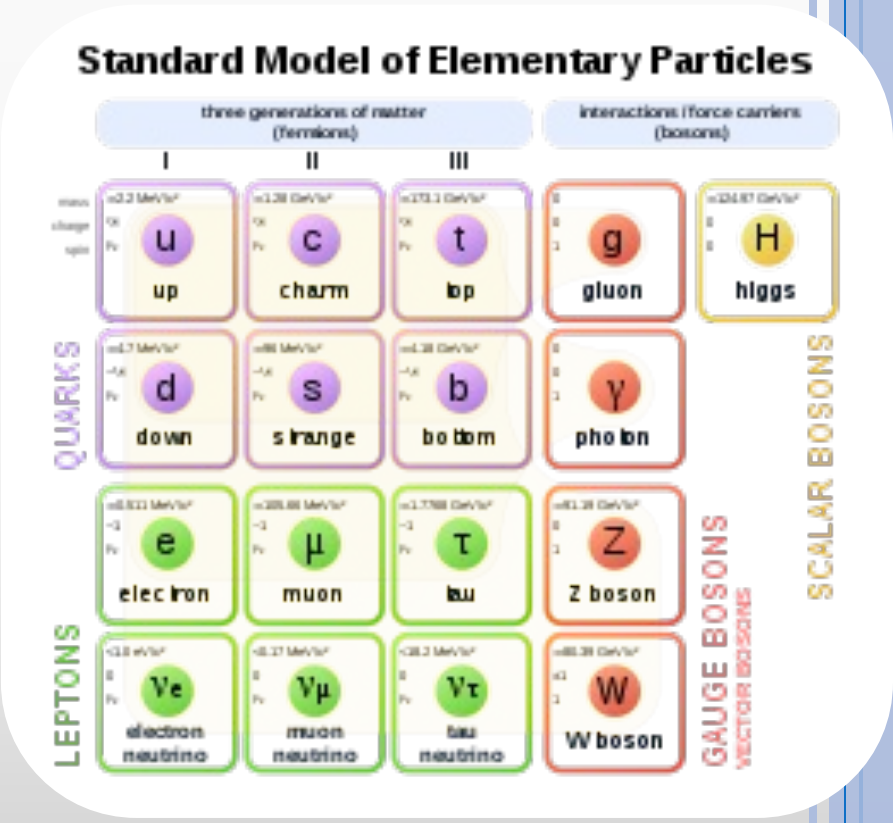
Search for physics BSM

The Standard Model

The Standard Model of particle physics is a successful theory of three (out of four) fundamental interactions that govern the universe: electromagnetism, the strong force, and the weak force.

It explains how all know matter is made of quarks and leptons which interact by force carrying particles: photons, gluons, W and Z.

Fundamental particles acquire mass through their interactions with the Higgs field



BEYOND THE STANDARD MODEL (BSM)

Why are we looking for physics BSM?

Fundamental questions to be addressed:

- Why there are three families of quarks and leptons?
- Why the masses of fundamental particles span several orders of magnitude?
- How to accommodate gravity into the global quantum picture?

Compelling empirical evidence that the standard model is incomplete!

- Dark matter
- Dark energy
- Non-zero mass of neutrinos
- Baryon asymmetry in the universe ➔

Sakharov's conditions

- Baryon Number Violation
- C-symmetry and CP-symmetry violation
- Loss of thermal equilibrium

Direct and Indirect BSM Searches

Direct Searches (Energy Frontier)

- Use of high-energy colliders (Tevatron, LHC, …) to produce new particles

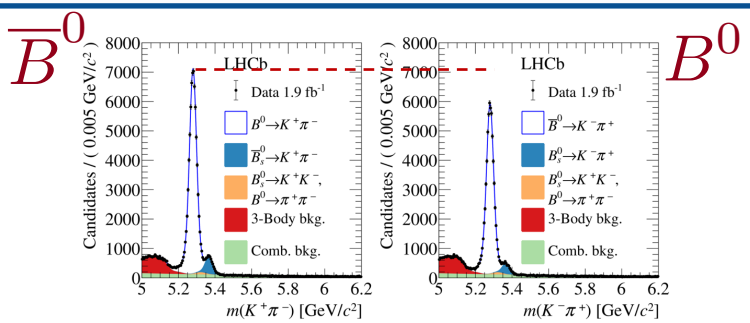
Indirect Searches (Intensity Frontier) ← **LHCb**

- Production of a huge numbers of particles (B-factories, LHC, …) needed to study very rare processes. Which ones?
  - SM prediction should have high precision
  - CP Violation → **Decays of *b* quark**
  - Lepton flavour / lepton number / lepton universality

LHCb RESULTS

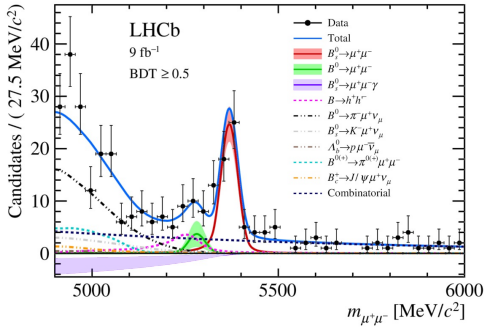
CP Violation

http://arxiv.org/abs/2012.05319



Search for Rare Decay $B_s \to \mu^+ \mu^-$

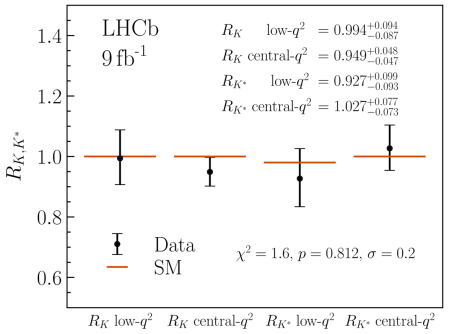
http://arxiv.org/abs/2108.09283



Test of Lepton Universality

$$R_K = \frac{B^+ \to K^+\mu^+\mu^-}{B^+ \to K^+e^+e^-} \qquad R_{K^*} = \frac{B^0 \to K^{*0}\mu^+\mu^-}{B^0 \to K^{*0}e^+e^-}$$

http://arxiv.org/abs/2212.09153 http://arxiv.org/abs/2212.09152



A Physics Program Embedded in a Logo

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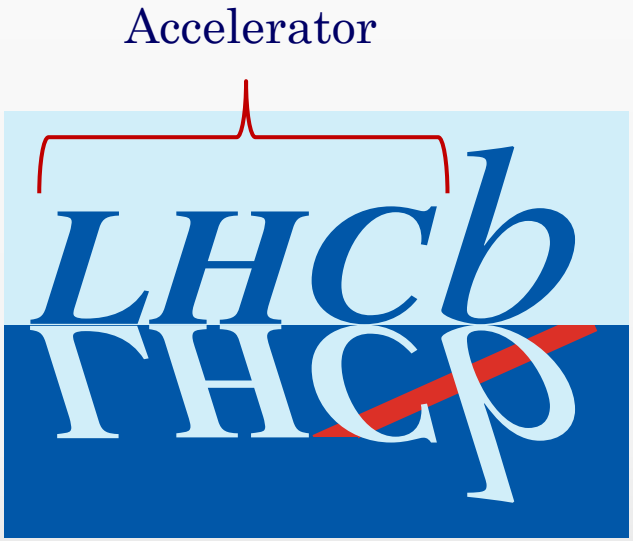

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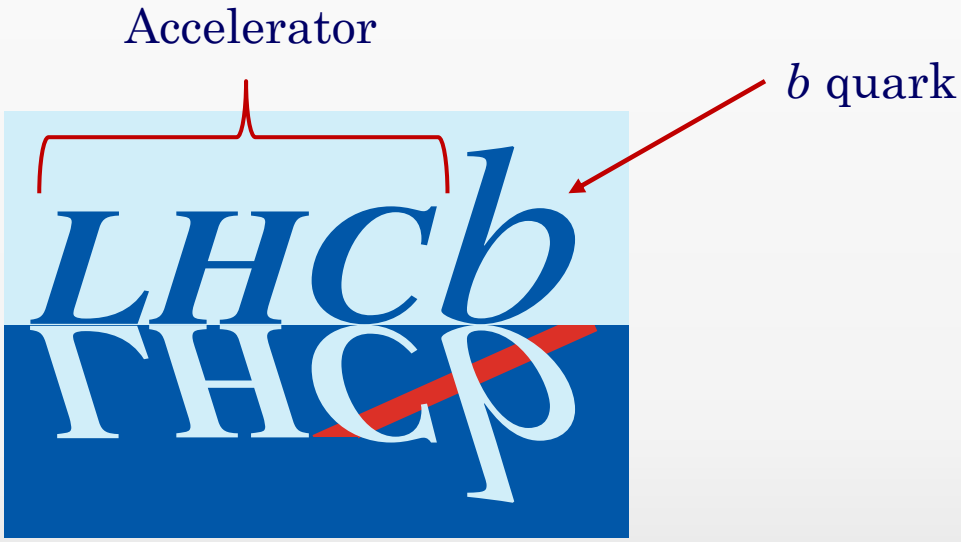

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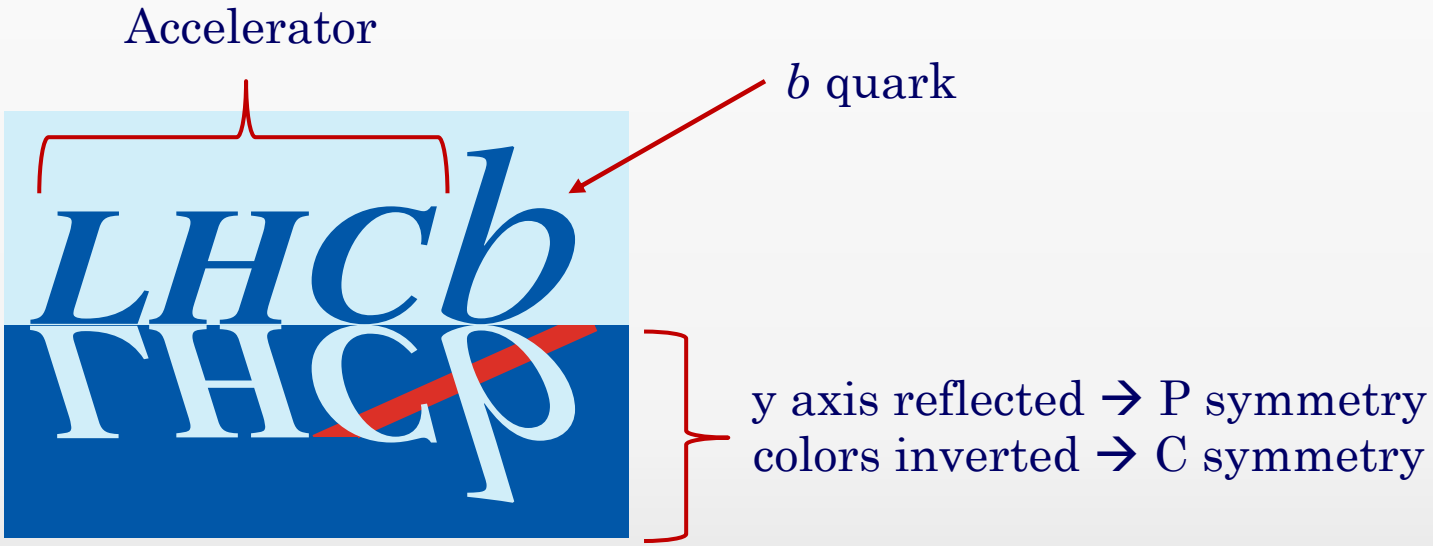


A Physics Program Embedded in a Logo

Accelerator

b quark

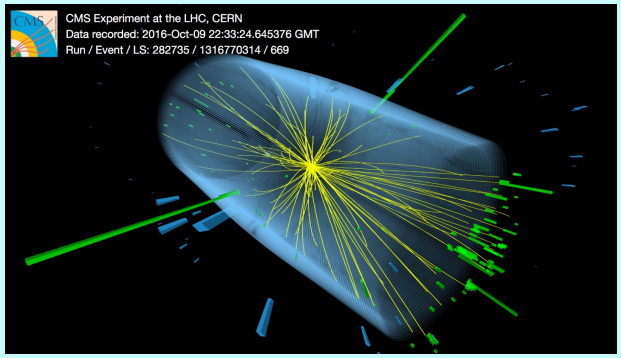
y axis reflected → P symmetry
colors inverted → C symmetry

CP violation !

EVENT TOPOLOGY AT LHC

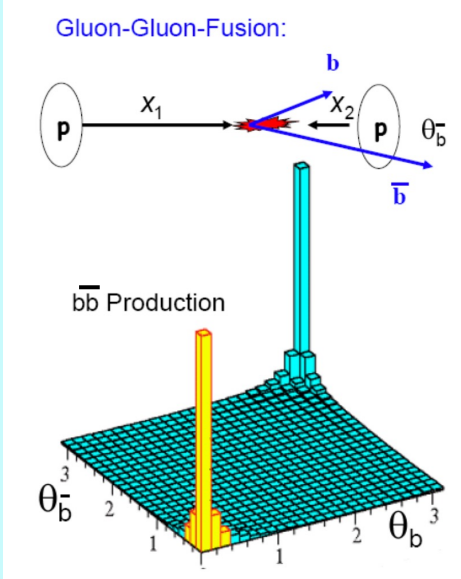
Direct Searches (Energy Frontier)

- H→ **γ γ** and search for X→ **γ γ**

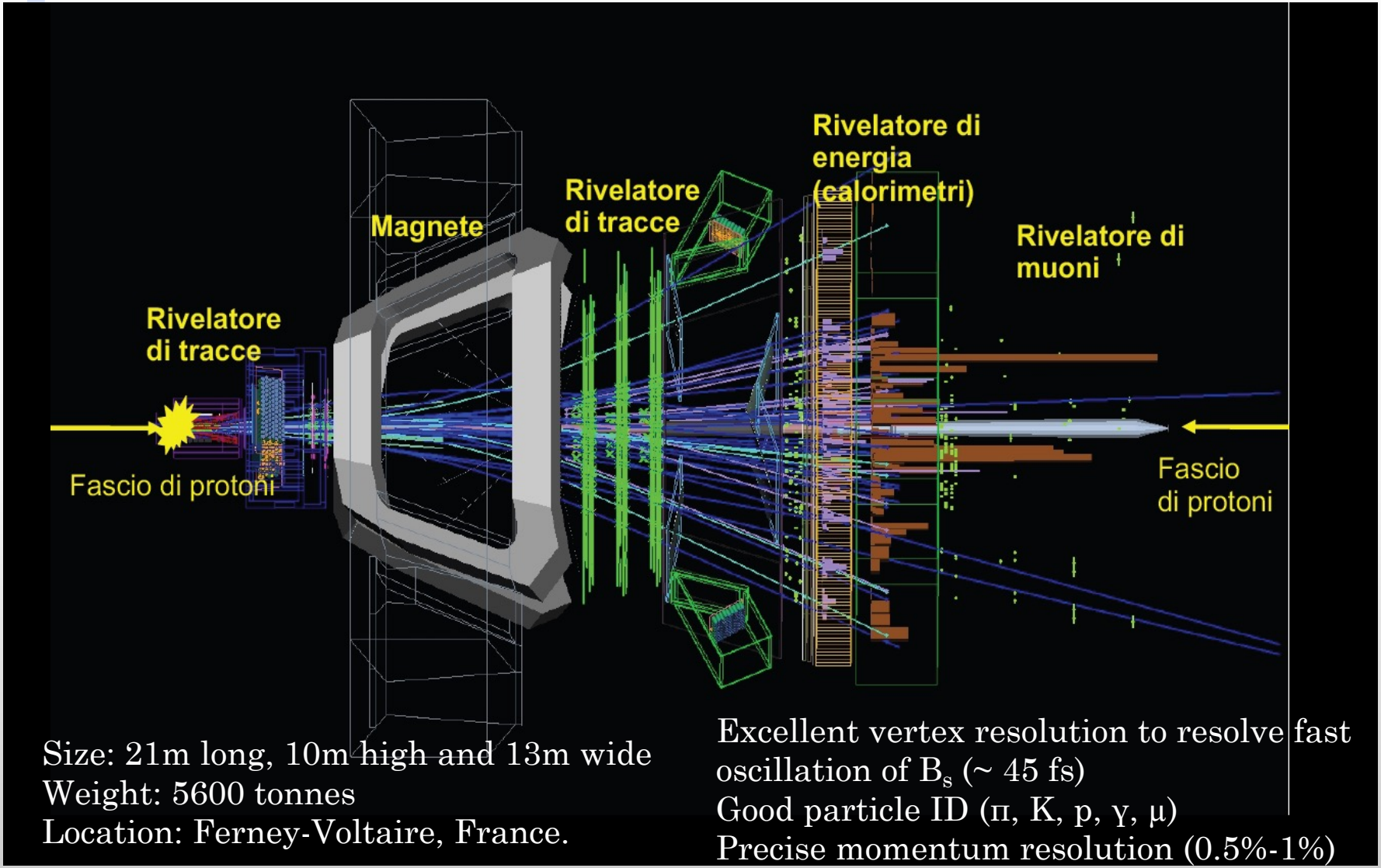


Indirect Searches (Intensity Frontier)

- Search for rare *b*-hadron decays



THE LHCb DETECTOR



Size: 21m long, 10m high and 13m wide
Weight: 5600 tonnes
Location: Ferney-Voltaire, France.

Excellent vertex resolution to resolve fast oscillation of B_s (~ 45 fs)
Good particle ID (π, K, p, γ, μ)
Precise momentum resolution (0.5%-1%)

The LHCb Muon Detector

- $P_c^+ \rightarrow J/\psi\ (\rightarrow \mu^+ \mu^-)\ p$
- $B_s \rightarrow \mu^+ \mu^-$
- $R_K = \dfrac{B^+ \rightarrow K^+ \mu^+ \mu^-}{B^+ \rightarrow K^+ e^+ e^-}$

THE LHCb MUON DETECTOR

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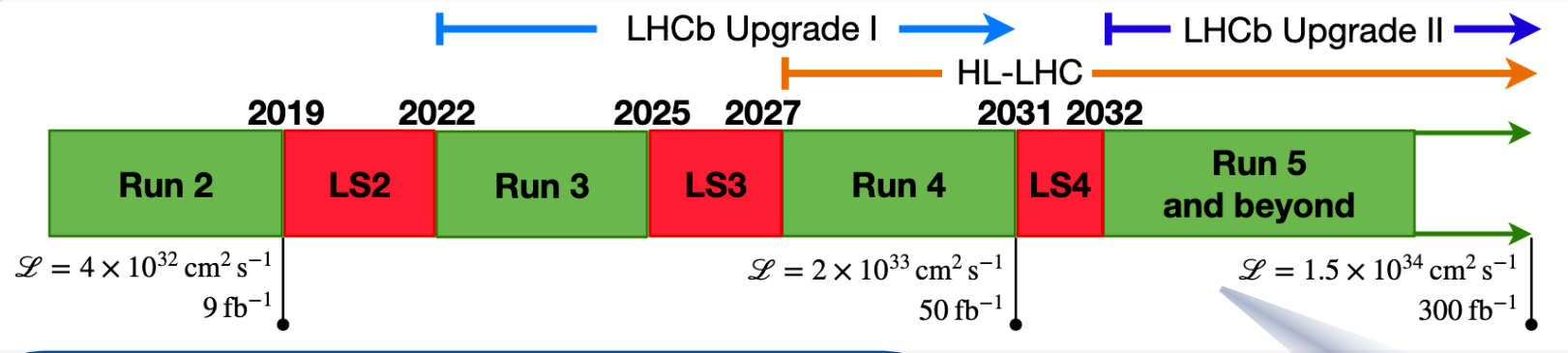
The LHCb Muon Detector is one of the largest and most irradiated detector in the world with 400 m^2 of sensitive area. It is crucial because

- Many physics channels identified by a μ signature
- Trigger

Excellent performance:

- Detection efficiency > 99% in all regions
- Muon ID efficiency ~ 97%

The Future of the LHCb Muon Detector



LHCb-U2@Bari

- → Estimate of U2 particle rates
- → New electronics
- → R&D on new-generation thin RPC detectors and new eco-friendly gas mixtures
- → Simulation studies on improved granularity, new read-out scheme, μ(mis-)ID
- → ….. and many others …