Search for radiative leptonic B^+ meson decays at LHCb

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FSP LHCb
Erforschung von
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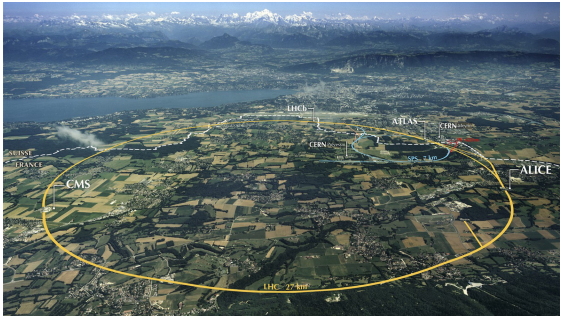
The LHCb experiment at the LHC

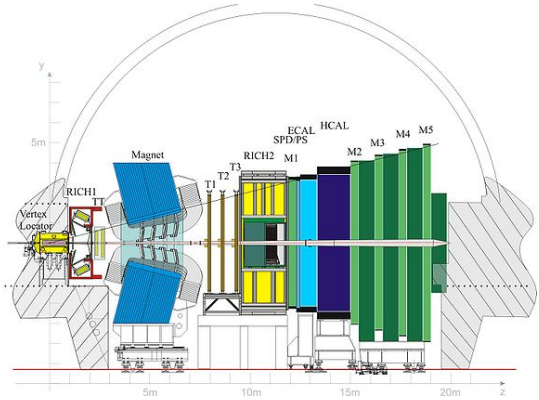
The Large Hadron Collider

- Most powerful particle accelerator to date
- Located at CERN near Geneva
- 27km accelerator 100m underground
- Proton beams accelerated to 0.99999999c
- Four main experiments to record particle collisions



The LHCb experiment

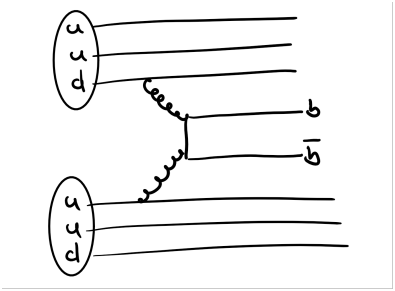
- One of four main experiments at the LHC
- Records proton-proton collisions at a rate of 40MHz
- Forward spectrometer
- LHCb is *beautiful*
- Designed to study decays of bound states including bottom quarks, e.g. $B^+(\bar{b}u), B^0(\bar{b}d), \Lambda_b(udb)$



The LHCb experiment

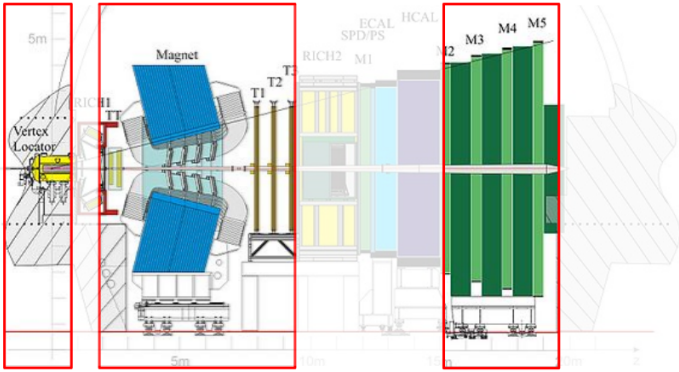
Why build a forward spectrometer?

- b quarks are produced in pairs $b\bar{b}$
- Production in gluon-gluon fusion
- Likely asymmetric momentum
- Boosted in forward (or backward) direction
- Produce many B^+ mesons (lifetime 10^{-12}s)
- B^+ flies a few mm in the detector before decaying



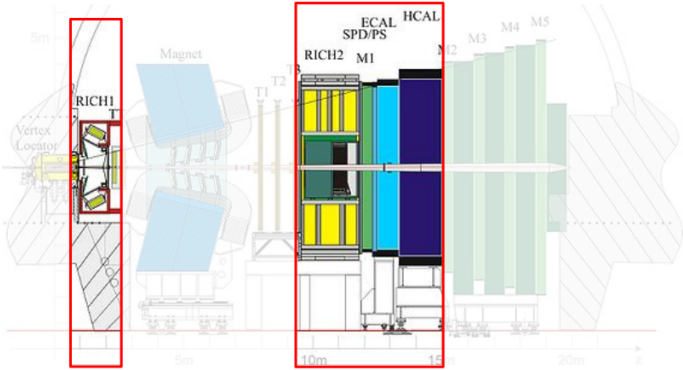
LHCb tracking system

- Tracking system consists of VELO, TT, Magnet, T1-T3, muon stations
- For charged particles
- Estimate momentum from curvature



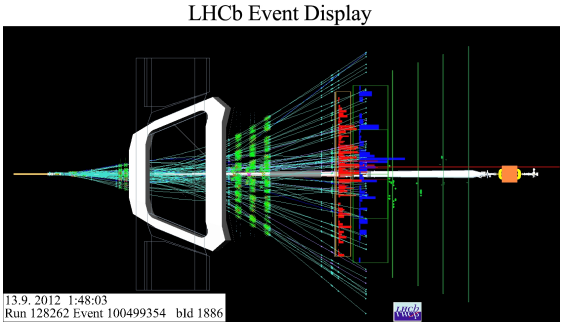
LHCb particle identification system

- Particle IDentification system consists of
  - Ring-Imaging Cherenkov (RICH) system
  - Electromagnetic and Hadronic Calorimeters
- Separation of $e^{\pm}, \pi^{\pm}, K^{\pm}, p, \pi^0, \gamma$

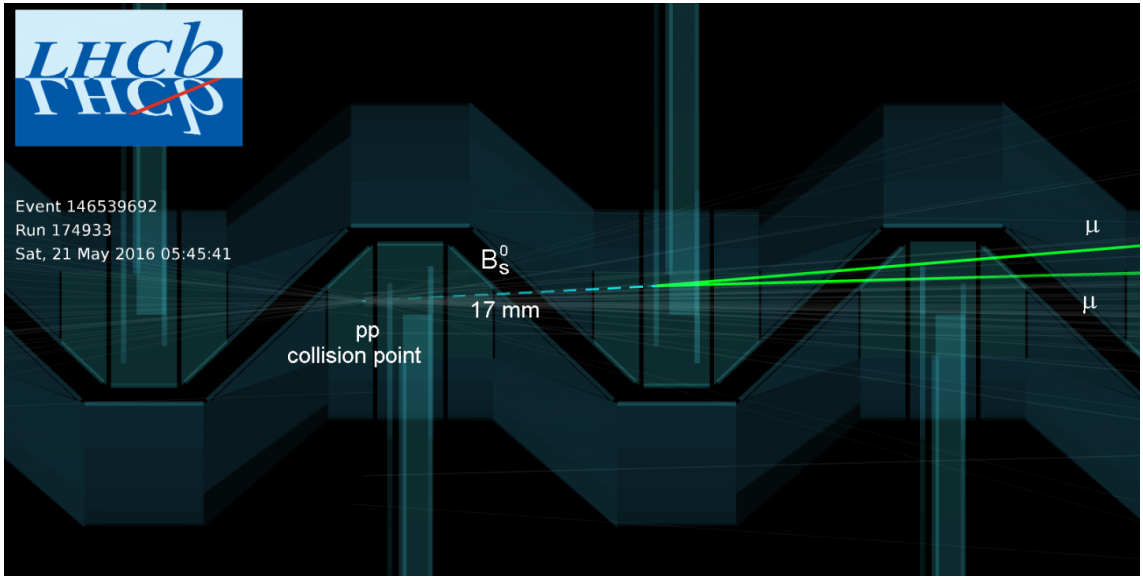


Event selection at LHCb

- Many particles produced in a single collision
- Lots of background events
- Recall: B mesons fly a few mm before decaying
- Search for displaced secondary vertices



Event selection at LHCb



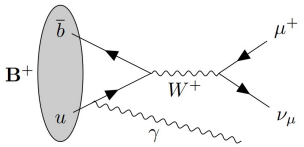
Search for radiative leptonic B^+ meson decays at LHCb

Radiative leptonic B^+ meson decays?

- B^+ meson is a bound state of a b and u quark
- Can only decay through weak interaction
- May decay to leptons e.g. $\mu^+\nu_\mu$ (*leptonic*)
- Can have emission of an additional photon (*radiative*)

- $B^+ \to \mu^+\nu_\mu\gamma$ has never been observed
- Upper limit on the branching fraction from Belle experiment [PRD 98 (2018) 11, 112016]

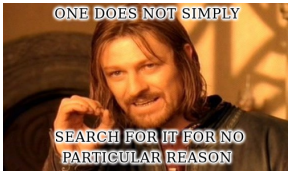
$$\mathcal{B}(B^+ \to \ell^+\nu_\ell\gamma) < 3.0 \times 10^{-6} \,@90\%\mathrm{CL}$$

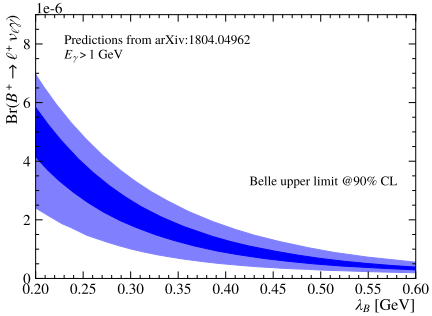


Leading order Feynman diagram for the decay $B^+ \to \mu^+\nu_\mu\gamma$.

Why search for $B^+ \to \mu^+ \nu_\mu \gamma$?

- Golden mode to probe B^+ meson substructure
- Access parameter λ_B which encodes QCD effects of bound B^+ meson state
- Value not well known but vital theory input
- Strong dependence of the branching fraction on λ_B

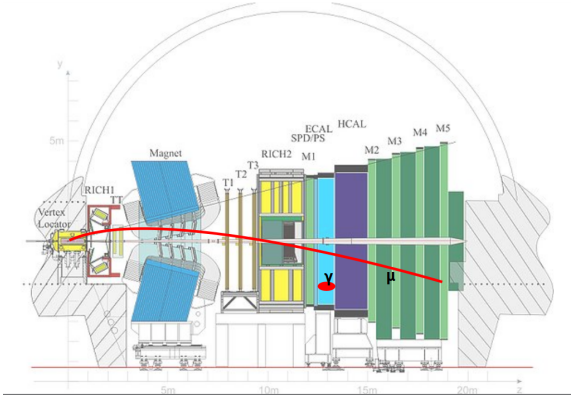




Problem with $B^+ \to \mu^+ \nu_\mu \gamma$

- Cannot reconstruct B^+ decay vertex from single charged track
- Cannot constrain neutrino momentum

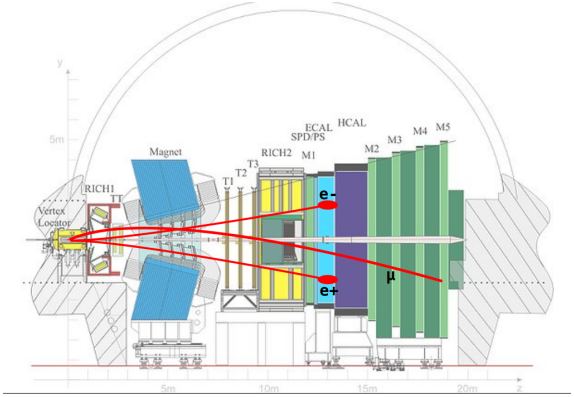
$\Rightarrow$ Search for $B^+ \to \mu^+ \nu_\mu \gamma$ deemed impossible at LHCb



Problem with $B^+ \to \mu^+ \nu_\mu \gamma$

A way out

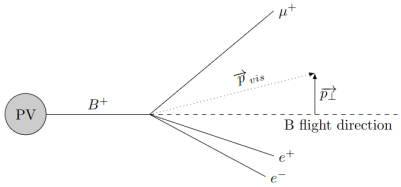
- Require photon conversion $\gamma \to e^+e^-$ in the VELO material
- Multiple charged tracks pointing to the B^+ decay vertex



A way out

- Neutrino momentum cannot be inferred from initial decay kinematics
- Correct for momentum imbalance perpendicular to B flight direction
- Require significant flight distance of B^+
- Excellent vertex reconstruction necessary

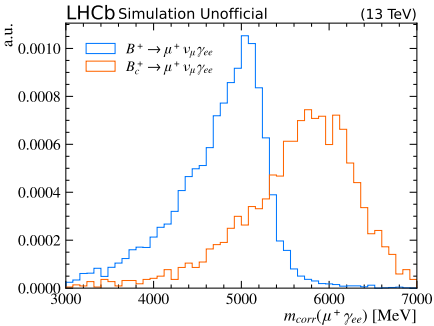
$$m_{corr} = \sqrt{m^2_{visible}(\mu^+\gamma_{ee}) + p^2_\perp} + p_\perp$$

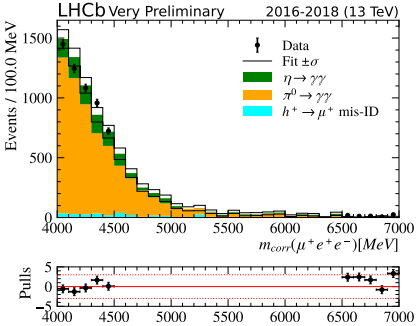


$\Rightarrow$ **Analysis becomes possible at LHCb**

What am I working on?

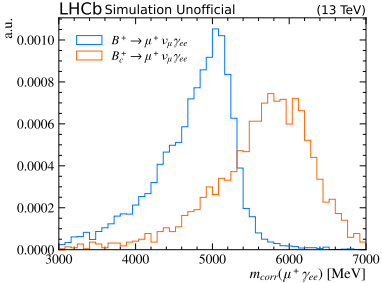
- Using data recorded with LHCb experiment from 2016-2018
- Search for signal peak in m_{corr}
- Study simulation samples
- Selection of signal candidates
- Understand and model the backgrounds
- To not bias ourselves the analysis is blinded



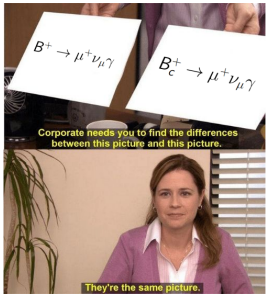


Two peaks?

- Figured there is another decay of $B_c^+ \to \mu^+ \nu_\mu \gamma$ possible
  - No one has ever searched for it
  - Not a single theory paper
  - Same final state → comes for free
  - Only accessible by LHCb



Corrected mass distribution for $B_{(c)}^+ \to \mu^+ \nu_\mu \gamma$ simulation. The grey area is the blinded signal region.



Summary

Hopefully, I could convince you that...

- There are many obstacles on the way to search for radiative leptonic B^+ meson decays at LHCb
- Analysis of $B^+ \to \mu^+ \nu_\mu \gamma$ is possible at LHCb, despite being deemed impossible
- LHCb allows for a unique search of $B_c^+ \to \mu^+ \nu_\mu \gamma$
- We are pushing the limits of the LHCb experiment with this effort
- Understanding the background shapes is key to this analysis
- There is still a lot of work to be done