ICHEP 2020 | PRAGUE

40th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

VIRTUAL CONFERENCE

28 JULY - 6 AUGUST 2020

PRAGUE, CZECH REPUBLIC

LHCb

LPNHE PARIS

Lepton Flavour Violation at LHCb

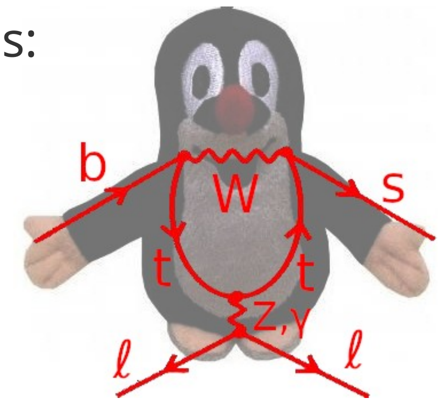
Steffen Weber, on behalf of the LHCb collaboration

Overview

- Motivation
- $B^+ \to K^+ \mu^\pm e^\mp$ Phys. Rev. Lett. 123 (2019) 241802
- $B^0_{(s)} \to \tau^\pm \mu^\mp$ Phys. Rev. Lett. 123 (2019) 211801
- $B^+ \to K^+ \mu^- \tau^+$(using B^{*0}_{s2}) JHEP 06 (2020) 129

Motivation

Krtek
~~Penguin~~ diagram



- Recent tensions with SM discovered by LHCb in b→sℓℓ transitions:
  - Ratios of branching ratios suggesting Lepton Flavour Universality Violations (LFUV) Phys. Rev. Lett. 122 (2019) 191801
  - Angular distributions Phys. Rev. Lett. 125 (2020) 011802
- Extensions of SM to explain LFUV naturally lead to sizable Lepton Flavour Violations Phys. Rev. Lett. 114 (2015) 091801
  - Leptoquarks JHEP 06 (2015) 072
  - Heavy gauge boson Z' Phys. Rev. D 92 (2015) 5, 054013
  - …
- While for the Standard Model, LFV processes are ~O(10^{-54})

→ Observation of LFV clear sign of Beyond Standard Model (BSM) physics

Selected LHCb results

$B^+ \to K^+ \mu^\pm e^\mp$

Phys. Rev. Lett. 123 (2019) 241802

Model expectations: $O(10^{-10})$ – $O(10^{-8})$

- Leptoquarks — JHEP 06 (2015) 072, JHEP 12 (2016) 027
- Extended gauge bosons — Phys. Rev. D92 (2015) 054013
- Neutrino CP violation — Phys. Lett. B750 (2015) 367

Best experimental limits so far

$B^+ \to K^+ \mu^+ e^-$: 13×10^{-8}
$B^+ \to K^+ \mu^- e^+$: 9.1×10^{-8}
@ 90% C.L. by BaBar PRD73 (2006) 092001

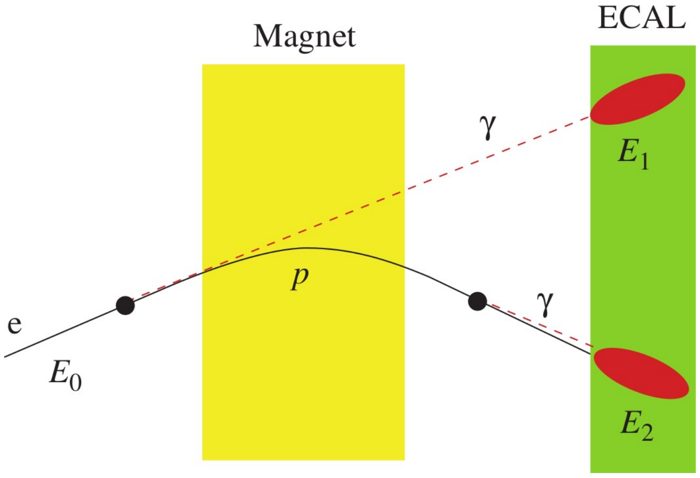
Analysis Strategy (Run1 data : 3 fb^{-1} @ 7, 8 TeV)

- Trigger on high p_T muon
- 3 charged tracks from common secondary vertex, incompatible with any PV, well identified as K, μ, e (using RICH, calorimeters, muon stations)
- Normalization/ control channel: $B^+ \to K^+ J/\psi(\to \mu\mu)$ / $B^+ \to K^+ J/\psi(\to ee)$

$B^+ \to K^+ \mu^\pm e^\mp$

Phys. Rev. Lett. 123 (2019) 241802

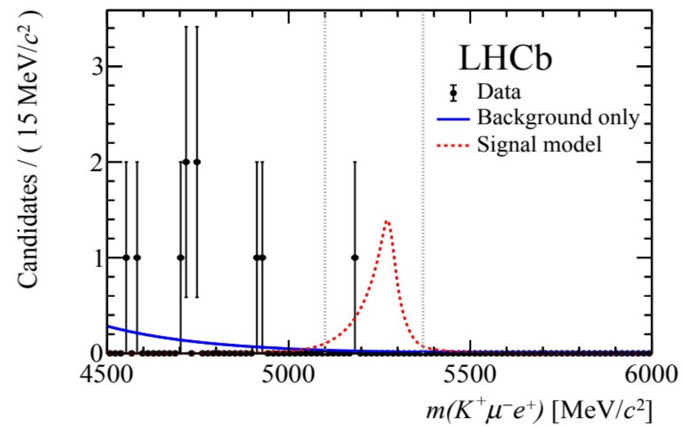
- Electron Identification
  - Electromagnetic calorimeters
  - Bremsstrahlung deteriorates resolution
  - Energy loss from bremsstrahlung partially recovered
  - Different fit functions for signal peak depending on whether photon recovered or not

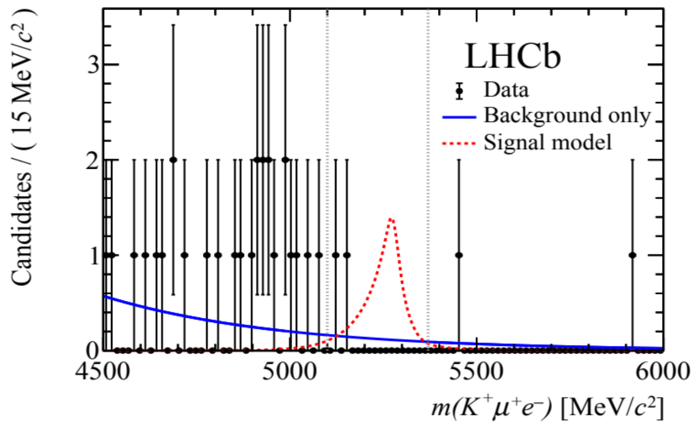


- Main backgrounds:
  - Bartially reconstructed B+ decays, e.g. $B^+ \to \overline{D}^0 (\to K\ell\nu X)\, \ell'\, \nu'\, X'$ → impose mass constraint $m(K^+\ell^-)>1885$ MeV
  - Charmonium with one lepton misidentified as K → mass vetoes
  - 2 BDTs against combinatorial and partially reconstructed background

$B^+ \to K^+ \mu^\pm e^\mp$

Phys. Rev. Lett. 123 (2019) 241802





- No enhancement in invariant mass region of signal observed
- Upper limits calculated with CLs method

J. Phys. G28 (2002) 2693

	90% C. L.	95% C. L.
$\mathcal{B}(B^+ \to K^+\mu^-e^+)/10^{-9}$	7.0	9.5
$\mathcal{B}(B^+ \to K^+\mu^+e^-)/10^{-9}$	6.4	8.8

← world’s best limit

← world’s best limit

$B^0_{(s)} \to \tau^\pm \mu^\mp$

Phys. Rev. Lett. 123 (2019) 211801

Model expectations: $O(10^{-9})$ – $O(10^{-5})$

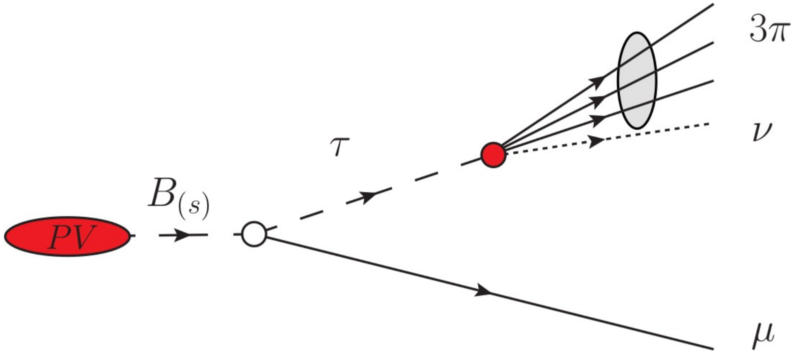
- Heavy neutral gauge boson — Eur. Phys. J. C 76 (2016) 134, PRD 92 (2015) 054013
- Leptoquarks — JHEP 6 (2015) 72, JHEP 11 (2016) 035, Mod. Phys.Lett. A 33 (2018) 1850019
- Three-site Pati-Salam — JHEP 2018 (2018) 148, JHEP 1907 (2019) 168

Best experimental limits so far

- $B^0 \to \tau^\pm \mu^\mp$: 2.2×10^{-5} @ 90% C.L. by BaBar — PRD 77 (2008) 091104
- $B^0_s \to \tau^\pm \mu^\mp$: no experimental limits yet

Analysis strategy (Run1 data : 3 fb^{-1} @ 7, 8 TeV)

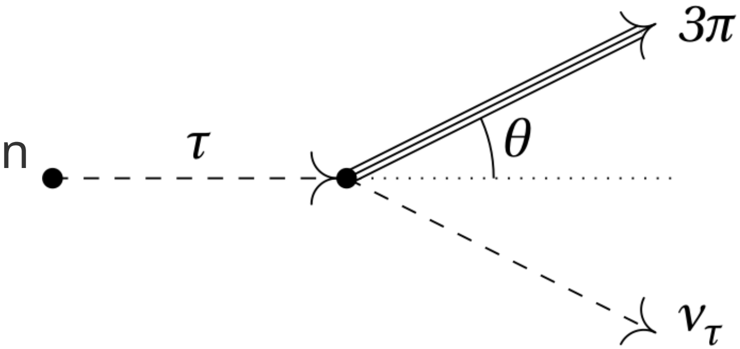
- Trigger on high p_T muon
- Reconstruct τ from $3\pi\nu$ decay
- Normalization channel: $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$

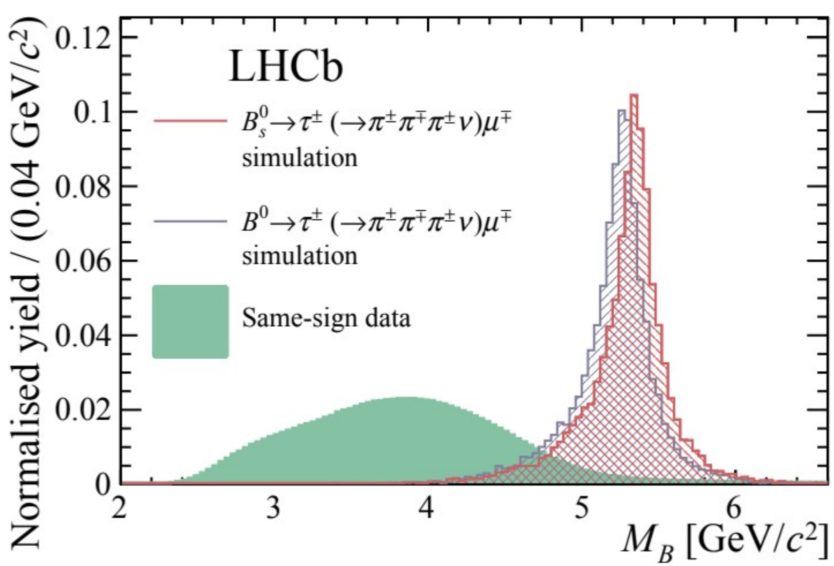


$B^0_{(s)} \rightarrow \tau^\pm \mu^\mp$

Phys. Rev. Lett. 123 (2019) 211801

- Can reconstruct τ momentum with 2-fold ambiguity via known flight direction, τ mass assumption, massless neutrino assumption
- τ decay mainly via a_1 and ρ resonances → helps to reduce background



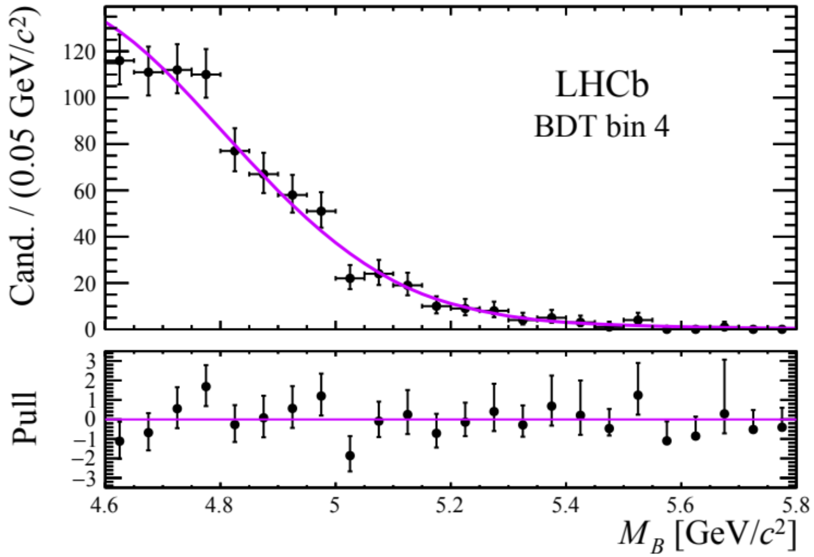


- Same-sign τμ pairs as model for combinatorial background
- Backgrounds from partially reconstructed B decays: distinguish with τ decay time, isolation variables, or suppress with mass vetoes
- B^0 and B_s^0 peaks overlap → perform search under B^0- or B_s^0- only hypotheses

$B^0_{(s)} \to \tau^\pm \mu^\mp$

Phys. Rev. Lett. 123 (2019) 211801

highest BDT bin



- Search performed in bins of final BDT output with increasing signal sensitivity
- No signal observed

Mode	90% CL	95% CL
$B^0_s \to \tau^\pm \mu^\mp$	3.4×10^{-5}	4.2×10^{-5}
$B^0 \to \tau^\pm \mu^\mp$	1.2×10^{-5}	1.4×10^{-5}

world's first limit

world's best limit

$B^+ \to K^+\mu^-\tau^+$ (using B_{s2}^{*0}) JHEP 06 (2020) 129

Model expectations: $O(10^{-9})$ – $O(10^{-5})$

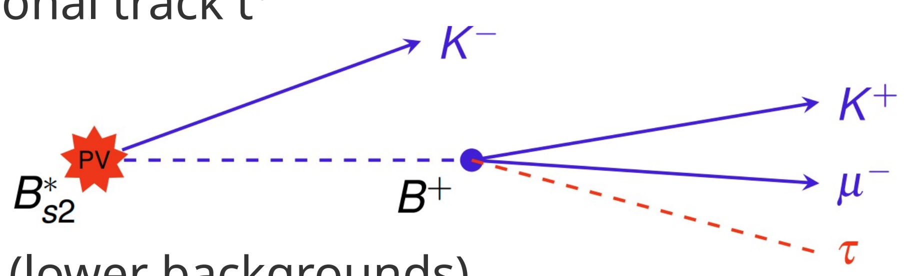
- Leptoquarks — Eur. Phys. J. C76 (2016) 67, PRD95 (2017) 035022, PRD96 (2017) 115011, JHEP 11 (2018) 081
- Three-site Pati-Salam — Phys. Lett. B779 (2018) 317, JHEP 10 (2018) 148

Best experimental limits so far

- 2.8×10^{-5} @ 90% C.L. by BaBar — Phys. Rev. D86 (2012) 012004

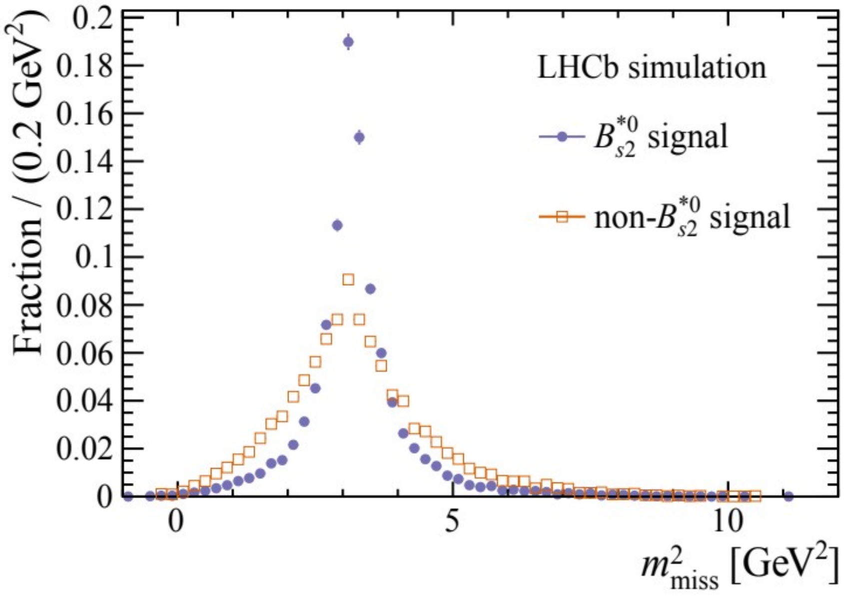
Analysis strategy (Run1 and Run2 data : 9 fb^{-1} @ 7, 8 and 13 TeV)

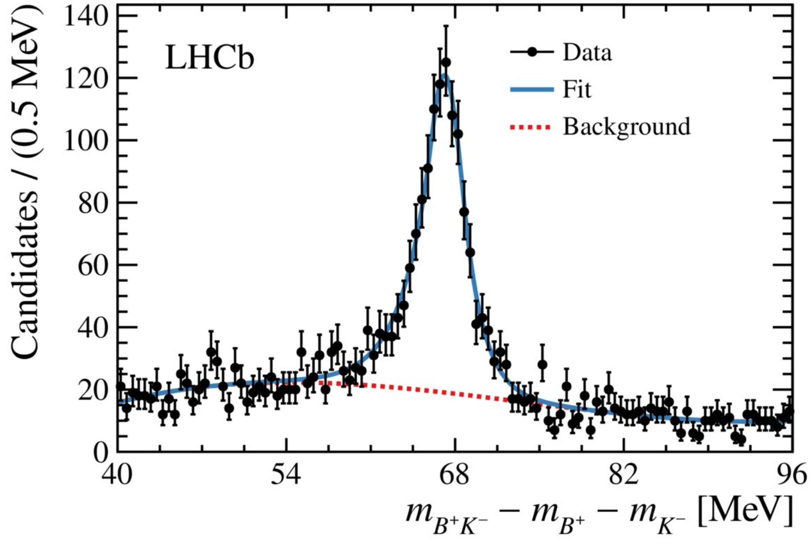
- Use $B_{s2}^{*0} \to B^+K^-$ decay: about 1% of B+ production
- $K^+\mu^-$ pair from secondary vertex plus additional track t$^+$
- Calculate missing mass squared in decay
  → expect peak at τ mass
- $K^+\mu^-\tau^+$ experimentally preferred over $K^+\mu^+\tau^-$ (lower backgrounds)



$B^+ \to K^+ \mu^- \tau^+$ (using B_{s2}^{*0}) JHEP 06 (2020) 129

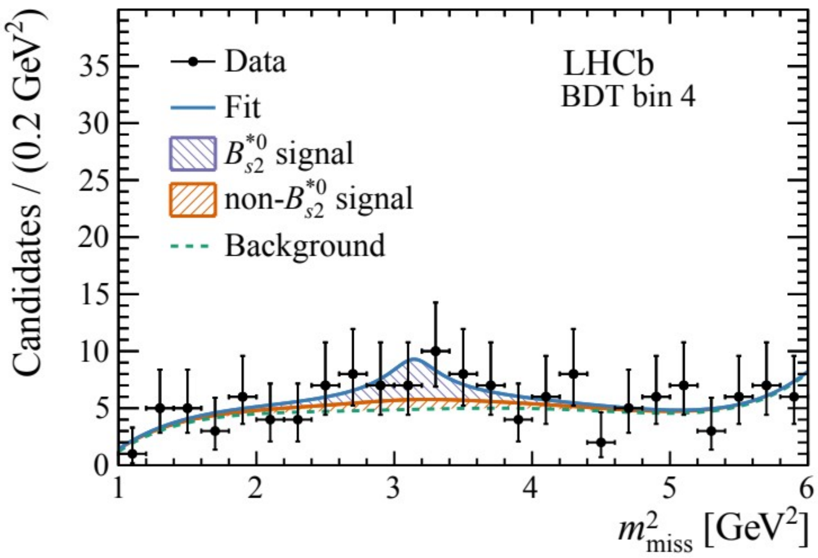
- Expect peak at τ mass also for B not from B_{s2}^{*0} decay, but wider distribution
- Normalization channel: $B^+ \to J/\psi(\to \mu\mu) K^+$
- Extract fraction of B^+ from B_{s2}^{*0} from B^+K^- invariant mass distribution
- Control sample: Same-sign B^+K^+ → to optimize signal selection, motivate background shape
- Backgrounds (different partially reconstructed b hadrons) suppressed with BDT
- Remaining backgrounds produce smooth m^2_{miss} distributions





$B^+ \to K^+\mu^-\tau^+$ (using B_{s2}^{*0}) JHEP 06 (2020) 129

highest BDT bin



- Search performed in bins of final BDT output with increasing signal sensitivity
- No signal observed
- Limits also expressed for signal model with modified decay kinematics

$$\mathcal{B}(B^+ \to K^+\mu^-\tau^+) < 3.9 \times 10^{-5} \text{ at } 90\% \text{ CL},$$
$$< 4.5 \times 10^{-5} \text{ at } 95\% \text{ CL}.$$

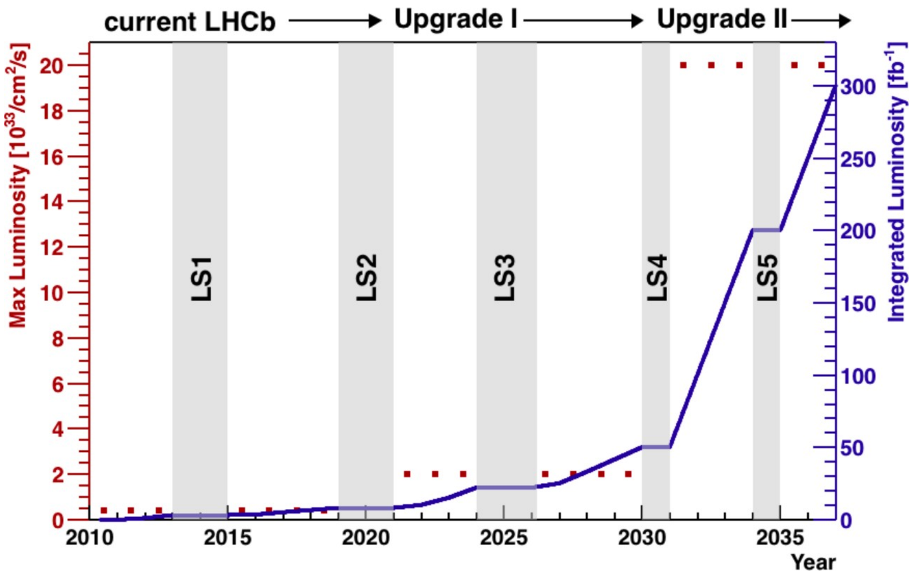
Conclusion

- Observation of LFV will be unambiguous sign of BSM physics
- Lowering experimental upper limits crucial to constrain phase space of theoretical models
- LHCb has rich LFV search program, often producing world's best upper limits, or close to
- Especially strong in channels including e's and μ's (UL ~10^{-9})

Outlook

- Acquire ~23 fb^{-1} in Run3 (50 fb^{-1} before Upgrade II)
- Software trigger

LHCB-PUB-2018-009



- LVF in baryons
  - Complementary information (e.g. different dynamics due to half-integer spin)
  - Baryons are abundantly produced at LHC
  - E.g. $\Lambda_b^0 \rightarrow \Lambda_0 e^{\pm} \mu^{\mp}$: LHCb analysis ongoing

Thank you for your attention!

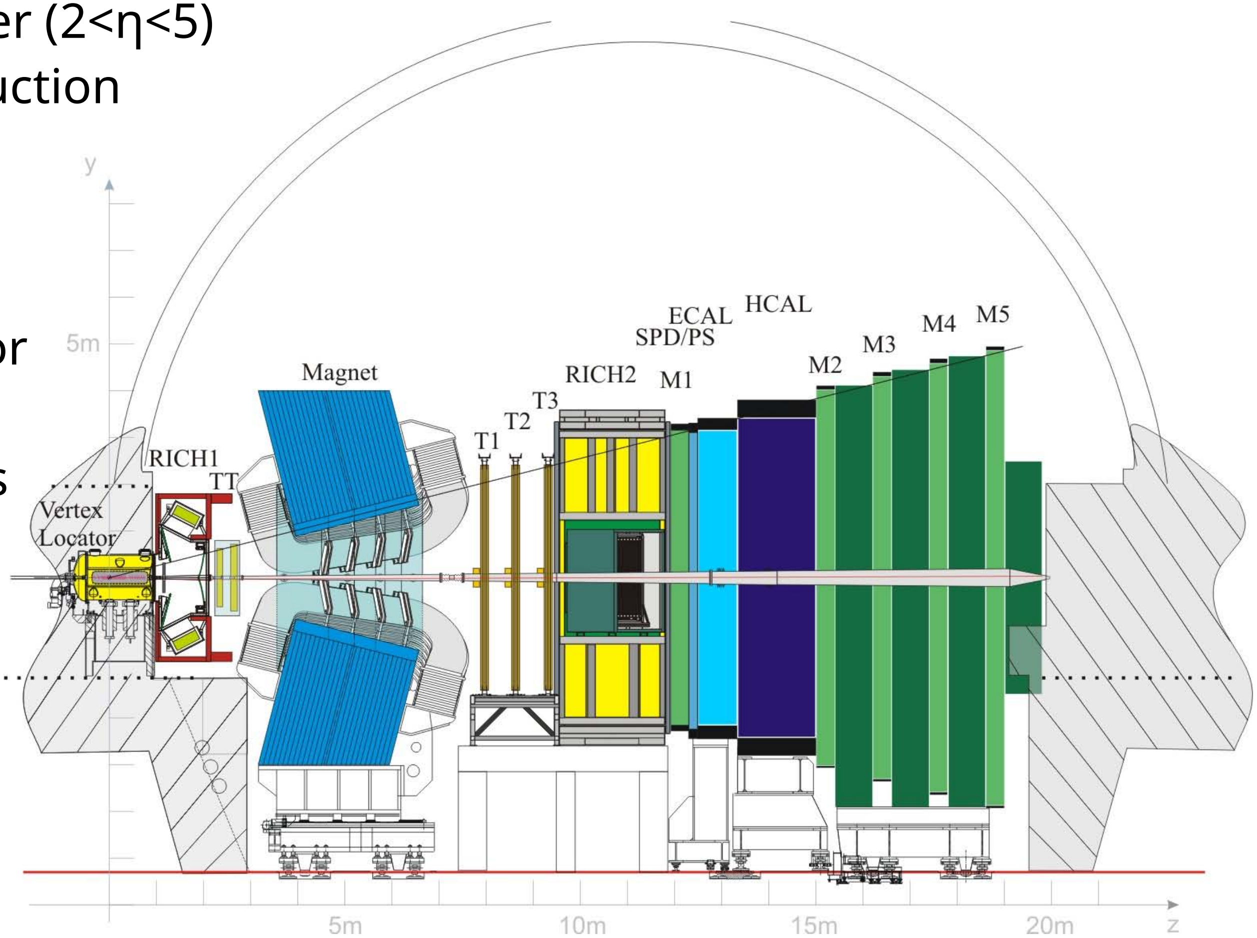
BACKUP

The LHCb detector

- Single arm forward spectrometer ($2<\eta<5$)
- Specialized on c and b reconstruction

- High precision tracking:
  - silicon strip vertex detector
  - large area silicon strip detector
  - 4 Tm dipole magnet
  - silicon strip + straw drift tubes downstream magnet

- PID
  - RICH, electromagnetic and hadronic calorimeters, muon stations



JINST 3 (2008) S08005
Int. J. Mod. Phys. A30 (2015) 1530022