Searches for rare decays and new physics at LHCb

报告人： 王辣

On behalf of the LHCb collaboration

中国物理学会高能物理分会学术年会
大连·辽宁师范大学

Outline

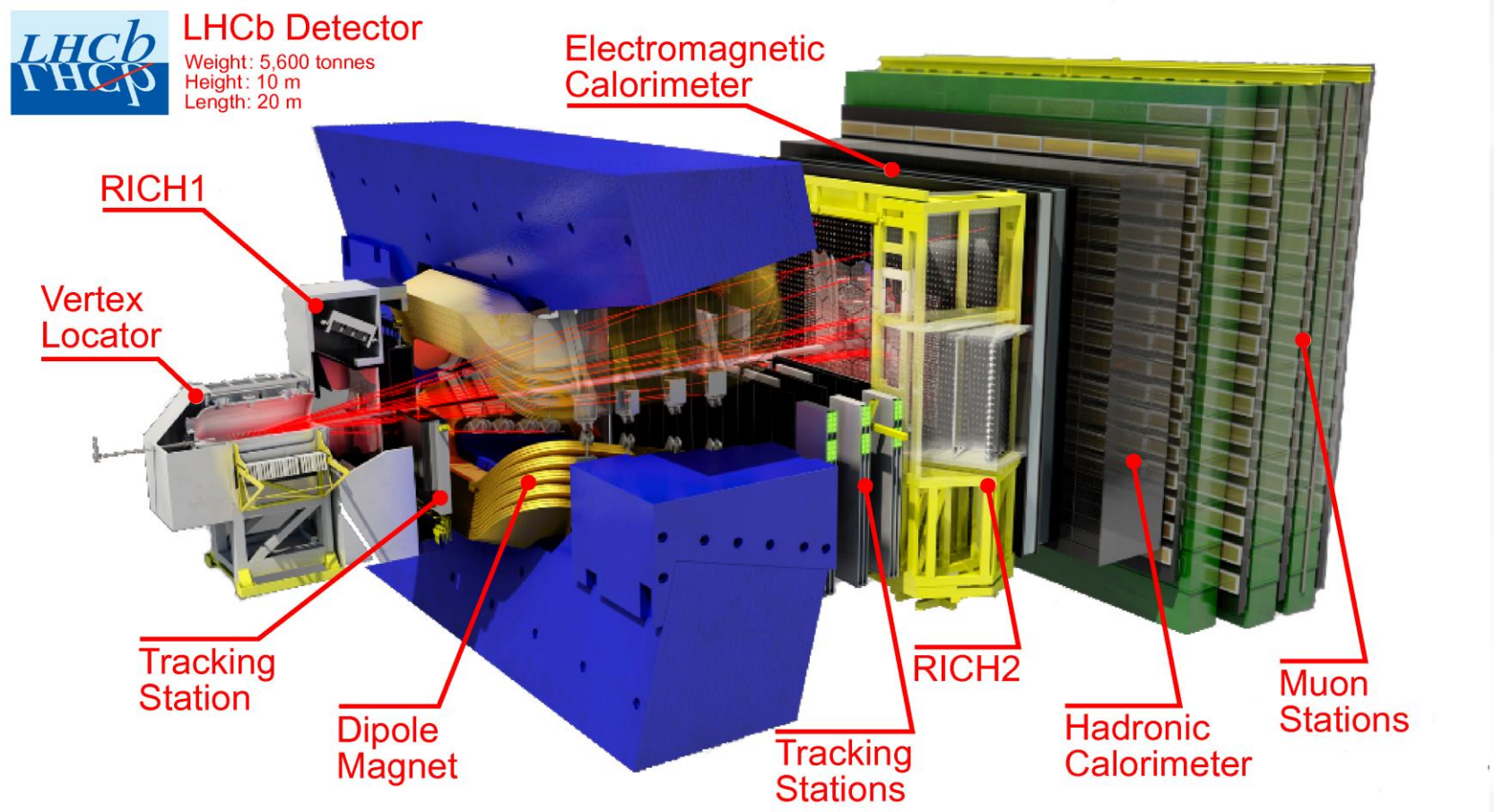
- Introduction
- $B_s^0 \to p\bar{p}$
- $B_{(s)}^0 \to p\bar{p}p\bar{p}$
- $B_{(s)}^0 \to p\mu^-$
- $B^0 \to \phi\mu^+\mu^-$
- Conclusions and outlook

Rare decay and new physics in b sector

Precisely measurement loop diagram for searching new particles that appear in the loop diagram

- Search new physics far above the accelerator collision energy
- Test new physics models, determining coupling constants and phases

LHCb detector



JINST 14 (2019) P11023, JINST 14 (2019) P04013, Int. J. Mod. Phys. A 30 (2015) 1530022, JINST 3 (2008) S08005

- Muon ID ~ 97 %
- Kaon ID ~ 95 %
- Electron ID ~ 90 %

- Track reconstruction efciency: ~ 96 %
- Momentum resolution: $\Delta p/p$ = 0.5 %
- Decay time resolution: ~45 fs for $B_s \to J/\psi\phi$

LHCb data

Collaboration

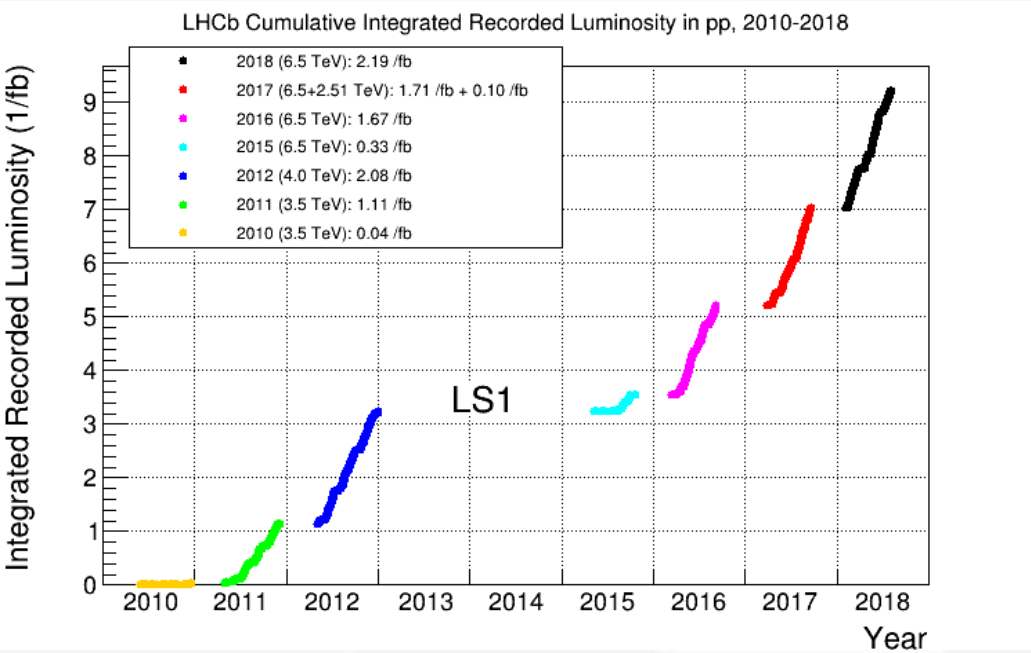
- 1477 members and 1011 authors
- 86 institutes

RD(LHCb) Publications

- 90(627) papers submitted
- 13562(49353) citations

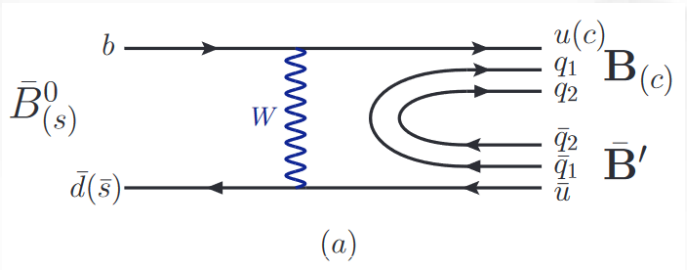
Data samples

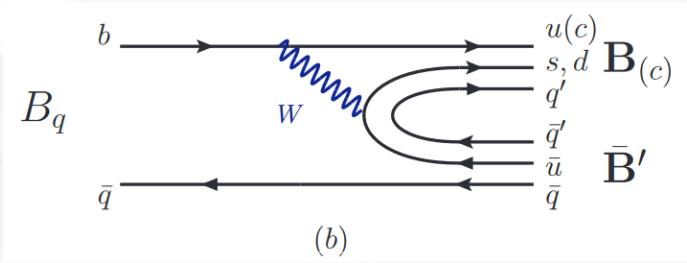
- Proton-proton collisions
  - 3 fb^{-1} at 7, 8 TeV
  - 6 fb^{-1} at 13 TeV
- Heavy-ion collisions
  - pPb, PbPb, (XeXe)

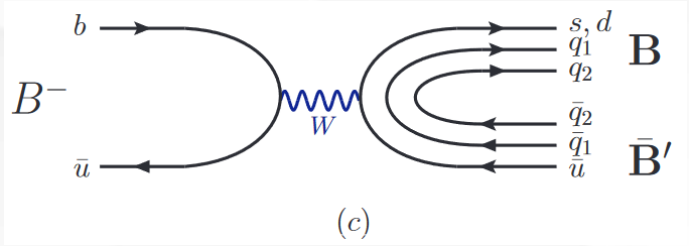


Search for the rare hadronic decay $B_s^0 \to p\bar{p}$ with Run2 data

- The two-body baryonic decay of the B meson occurs mainly through the following processes(JHEP04(2020)035):
  - (a): W–exchange
  - (b): internal W-emission
  - (c): W annihilation
- PRD.89.056003 and PRD.95.096004 point out that (a)(c) contributions could be neglected, but JHEP04(2020)035 argue that (a) contributions could yield $\mathcal{B}(B_s^0 \to p\bar{p}) \sim 10^{-8}$

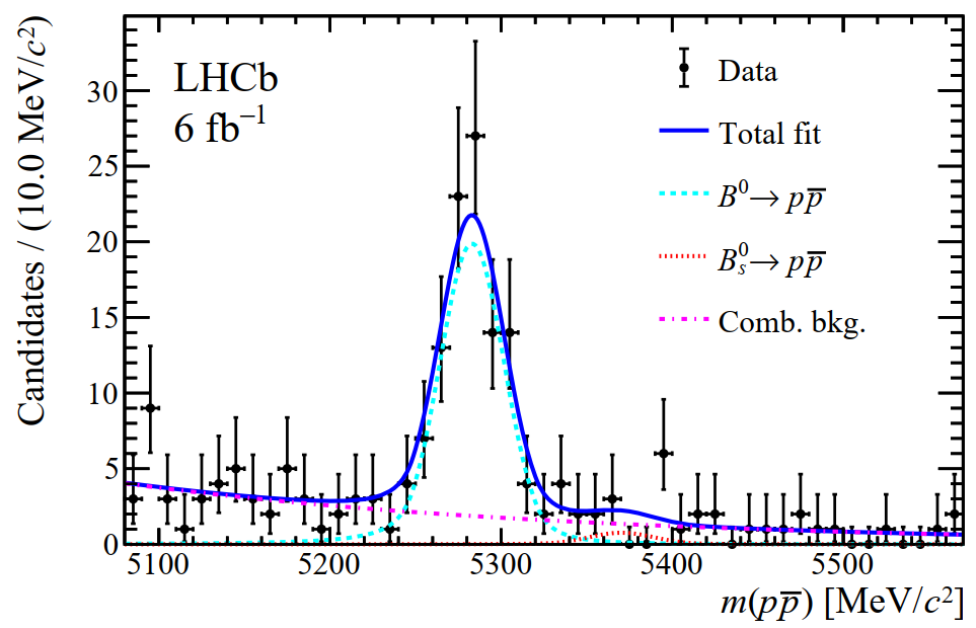






Search for the rare hadronic decay $B_s^0 \to p\bar{p}$ with Run2 data

- No evidence of the $B_s^0 \to p\bar{p}$ is found
- Updated $\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.13 \pm 0.05 \pm 0.03) \times 10^{-8}$
- $\mathcal{B}(B_s^0 \to p\bar{p}) < 4.4(5.1) \times 10^{-9}$@90(95)%CL
- $\mathcal{B}(B_s^0 \to p\bar{p}) < 1.5 \times 10^{-8}$@90%CL with Run1 data



arxiv:2206.07622,

Searches for the rare hadronic decays

$B^0 \to p\bar{p}p\bar{p}$ and $B_s^0 \to p\bar{p}p\bar{p}$ (Run1+Run2)

$\mathcal{B}(B \to hh')$ compare with $\mathcal{B}(B \to p\bar{p}hh')$

Threshold enhancement effect at:
$m(p\bar{p}) = m(p) + m(\bar{p})$

- ✓ $\mathcal{B}(B^0 \to \pi^+\pi^-) = (5.1 \pm 0.2) \times 10^{-6}$
- ✓ $\mathcal{B}(B^0 \to K^+\pi^-) = (2.0 \pm 0.1) \times 10^{-6}$
- ✓ $\mathcal{B}(B^0 \to K^+K^-) = (7.8 \pm 0.5) \times 10^{-8}$
- ✓ $\mathcal{B}(B^0 \to p\bar{p}) = (1.3 \pm 0.3) \times 10^{-8}$

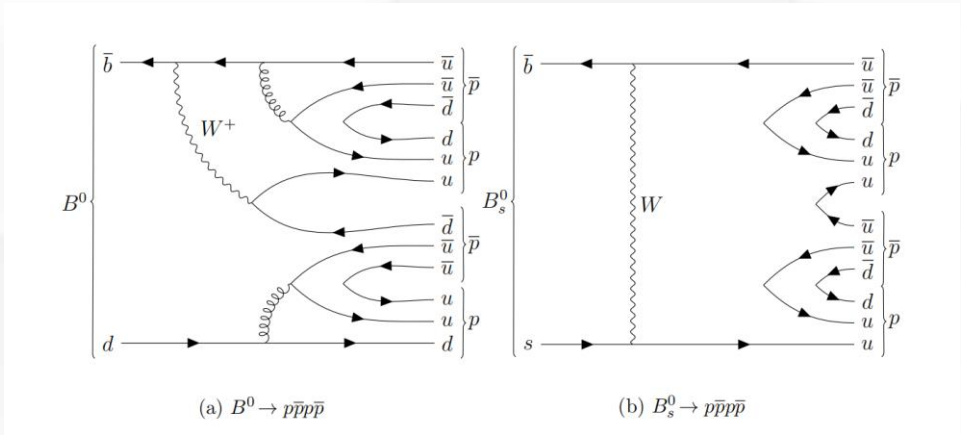
$\mathcal{B}(B^0 \to p\bar{p}\pi^+\pi^-) = (2.9 \pm 0.2) \times 10^{-6}$
$\mathcal{B}(B^0 \to p\bar{p}K^+\pi^-) = (6.3 \pm 0.5) \times 10^{-6}$
$\mathcal{B}(B^0 \to p\bar{p}K^+K^-) = (1.2 \pm 0.3) \times 10^{-7}$
$\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) < (2.0) \times 10^{-7}$

- ✓ $\mathcal{B}(B_s^0 \to \pi^+\pi^-) = (7.0 \pm 1.0) \times 10^{-7}$
- ✓ $\mathcal{B}(B_s^0 \to K^+\pi^-) = (5.8 \pm 0.7) \times 10^{-6}$
- ✓ $\mathcal{B}(B_s^0 \to K^+K^-) = (2.7 \pm 0.2) \times 10^{-5}$
- ✓ $\mathcal{B}(B_s^0 \to p\bar{p}) < (4.4) \times 10^{-9}$

$\mathcal{B}(B_s^0 \to p\bar{p}\pi^+\pi^-) = (4.3 \pm 2.0) \times 10^{-7}$
$\mathcal{B}(B_s^0 \to p\bar{p}K^+\pi^-) = (1.4 \pm 0.3) \times 10^{-6}$
$\mathcal{B}(B_s^0 \to p\bar{p}K^+K^-) = (4.5 \pm 0.5) \times 10^{-6}$
$\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = ?$

Searches for the rare hadronic decays $B^0 \to p\bar{p}p\bar{p}$ and $B_s^0 \to p\bar{p}p\bar{p}$ (Run1+Run2)

- Interesting patterns in rates with or without $p\bar{p}$ pairs in final state:
  - $\mathcal{B}(B^0 \to p\bar{p}) = (1.3 \pm 0.3) \times 10^{-8}$, considering threshold enhancement effect at $B^0 \to p\bar{p}p\bar{p}$, $\mathcal{B}(B^0 \to p\bar{p}p\bar{p})$ may be on the same order of magnitude
  - $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) < 2 \times 10^{-7}$@90CL given by BaBar(PhysRevD.98.071102)
- $B_s^0 \to p\bar{p}p\bar{p}$ has never been observed, $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p})$ is expected to be further suppressed with respect to B^0:
  - **Hadronisation fraction $f_s/f_d \sim 25\%$, and $|V_{us}/V_{ud}|^2 \sim 5\%$**

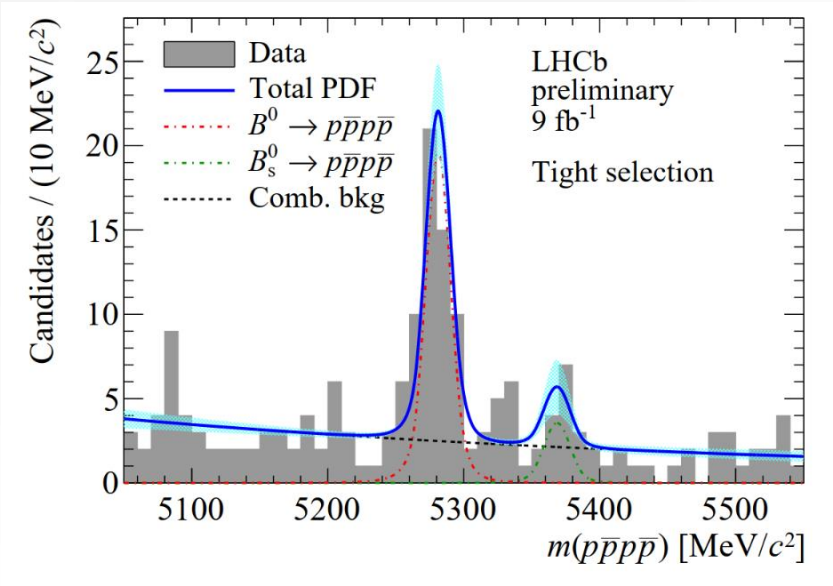


(a) $B^0 \to p\bar{p}p\bar{p}$ (b) $B_s^0 \to p\bar{p}p\bar{p}$

Searches for the rare hadronic decays $B^0 \to p\bar{p}p\bar{p}$ and $B_s^0 \to p\bar{p}p\bar{p}$ (Run1+Run2)

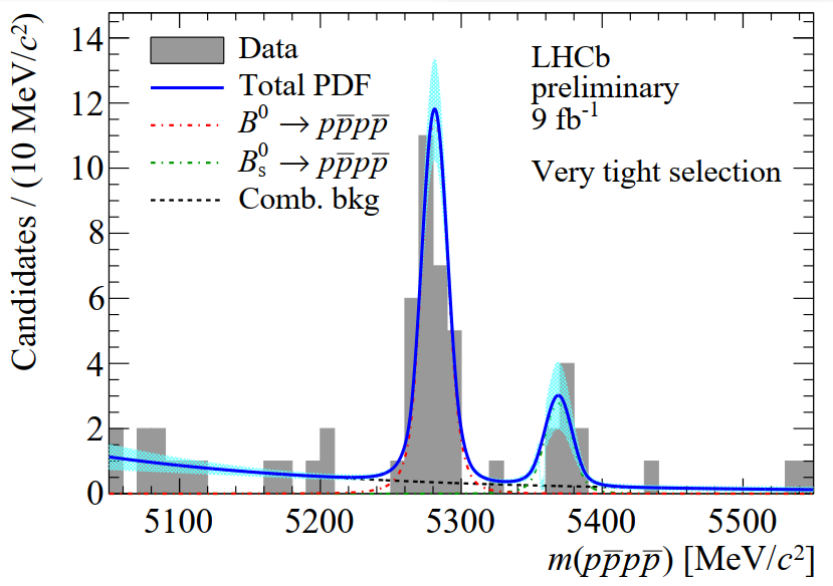
First observation of a purely baryonic 4-body decay :

- First observation: $\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$
- **Unexpectedly large** $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = (2.3 \pm 1.0 \pm 0.2 \pm 0.1) \times 10^{-8}$



$N(B^0 \to p\bar{p}p\bar{p}) = 48 \pm 8$

Significance: $> 9\sigma$



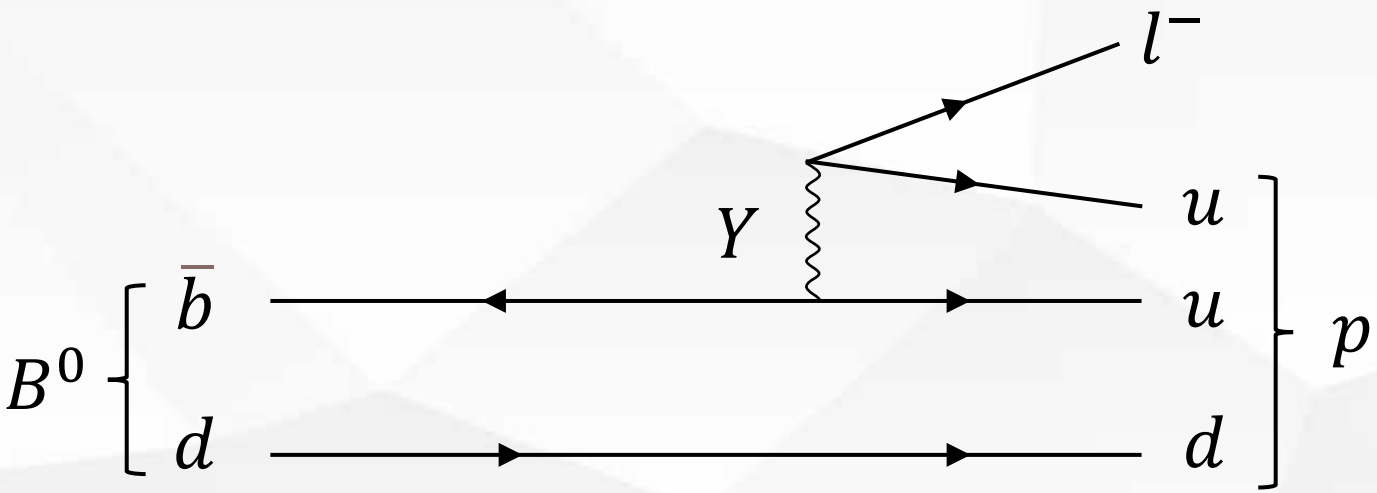
$N(B_s^0 \to p\bar{p}p\bar{p}) = 7 \pm 3$

Significance: 4σ

LHCb-PAPER-2022-032,

Search for the baryon and lepton number violating decays $B^0_{(s)} \to p\mu^-$ (Run1+Run2)

- Highly suppressed in SM, $\mathcal{B}(b \to uul^-) < 2.4 \times 10^{-27}$ in SM theoretical prediction, see PRD.72.095001
- Grand Unified Theory (GUT) models: hypothetical gauge bosons, X and Y, with electric charges of $\pm\frac{4}{3}e$ and $\pm\frac{1}{3}e$



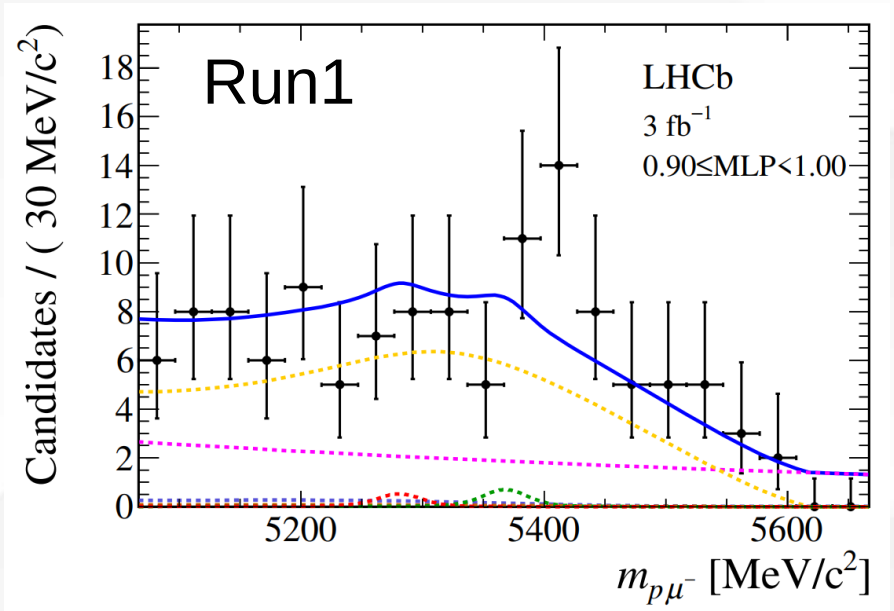
LHCb-PAPER-2022-022, to be submitted to JHEP

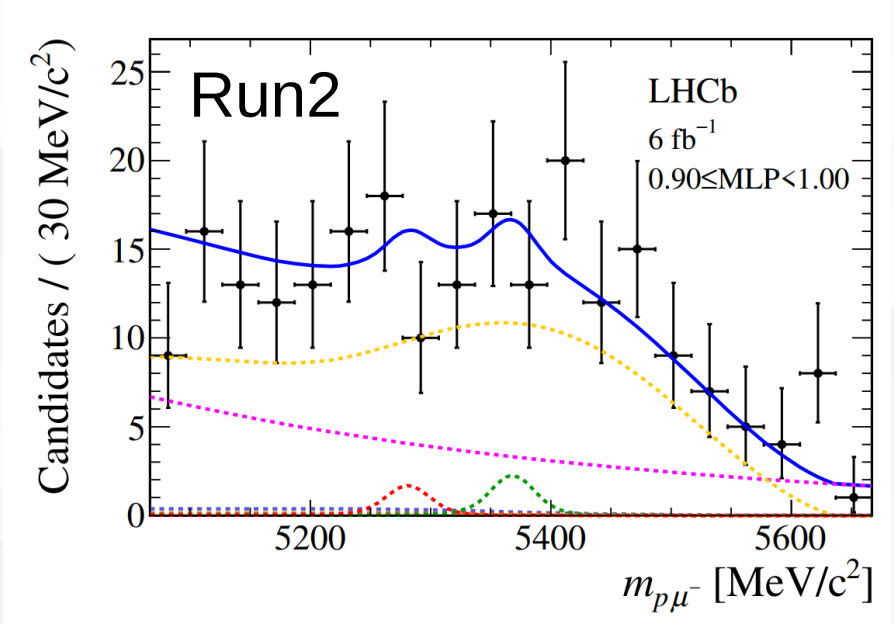
Feynman diagram of $B^0 \to pl^-$ mediated by a hypothetical Y boson.

Search for the baryon and lepton number violating decays $B^0_{(s)} \to p\mu^-$ (Run1+Run2)

- No signifcant signal for $B^0_{(s)} \to p\mu^-$ and is found
- $\mathcal{B}(B^0 \to p\mu^-) < 2.6(3.1) \times 10^{-9}$@90(95)%CL
- $\mathcal{B}(B^0_s \to p\mu^-) < 1.2(1.4) \times 10^{-8}$@90(95)%CL
- Compatible with the SM prediction

LHCb-PAPER-2022-022,
to be submitted to JHEP



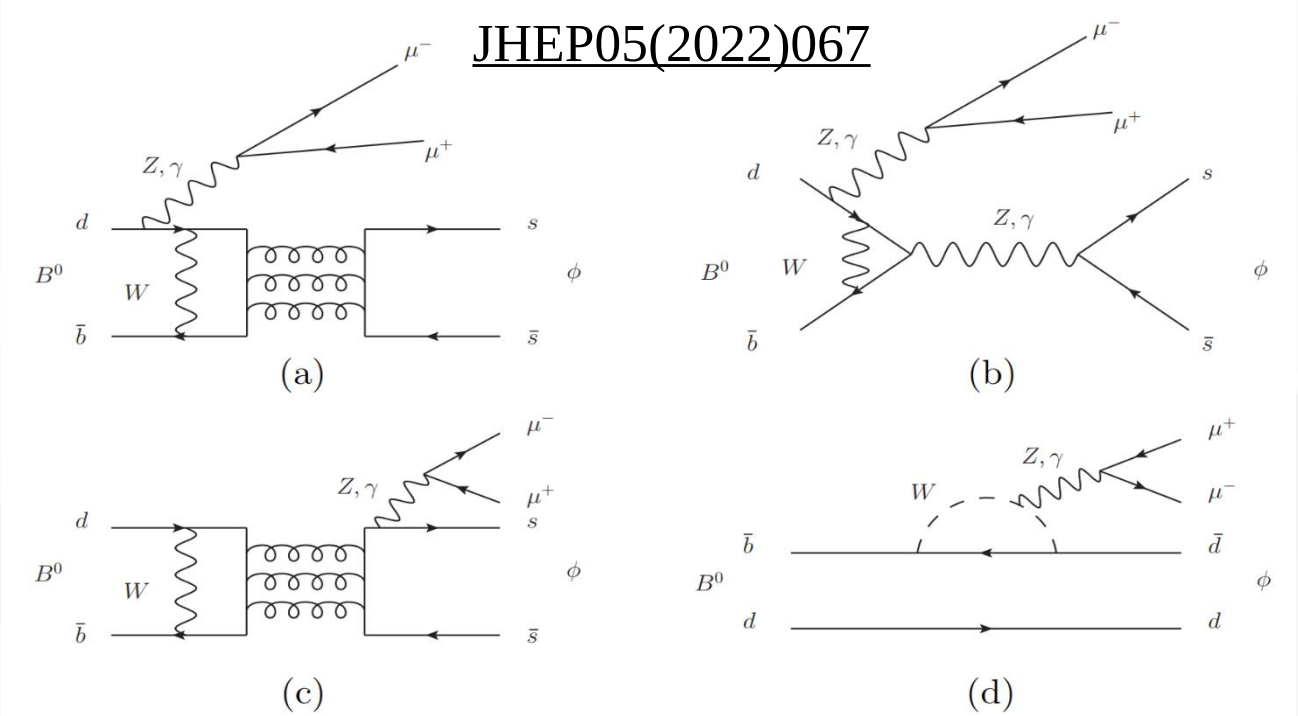


Search for the decay $B^0 \to \phi\mu^+\mu^-$ (Run1+Run2)

Standard Model Feynman diagrams for the decay $B^0 \to \phi\mu^+\mu^-$:

- $(a), (b), (c)$ represent the weak annihilation contributions, strongly suppressed in the SM, in the order of 10^{-12}
- (d) represents the contribution from $\omega - \phi$ mixing, if considering soft-collinear effective theory, $\mathcal{B}(B^0 \to \phi\mu^+\mu^-)$ predicted to be between 10^{-11} to 10^{-10} (PRD.103.076004)

JHEP05(2022)067



Search for the decay $B^0 \to \phi\mu^+\mu^-$ (Run1+Run2)

- No evidence for the $B^0 \to \phi\mu^+\mu^-$ decay is found
- $\mathcal{B}(B^0 \to \phi\mu^+\mu^-) < 3.2 \times 10^{-9}$@90%CL
- Compatible with the SM prediction

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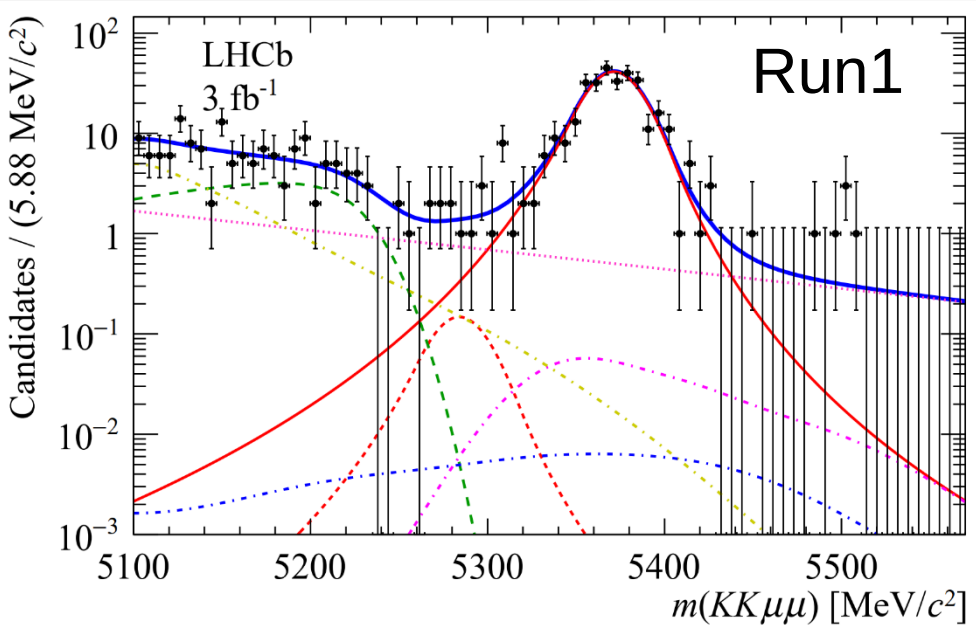
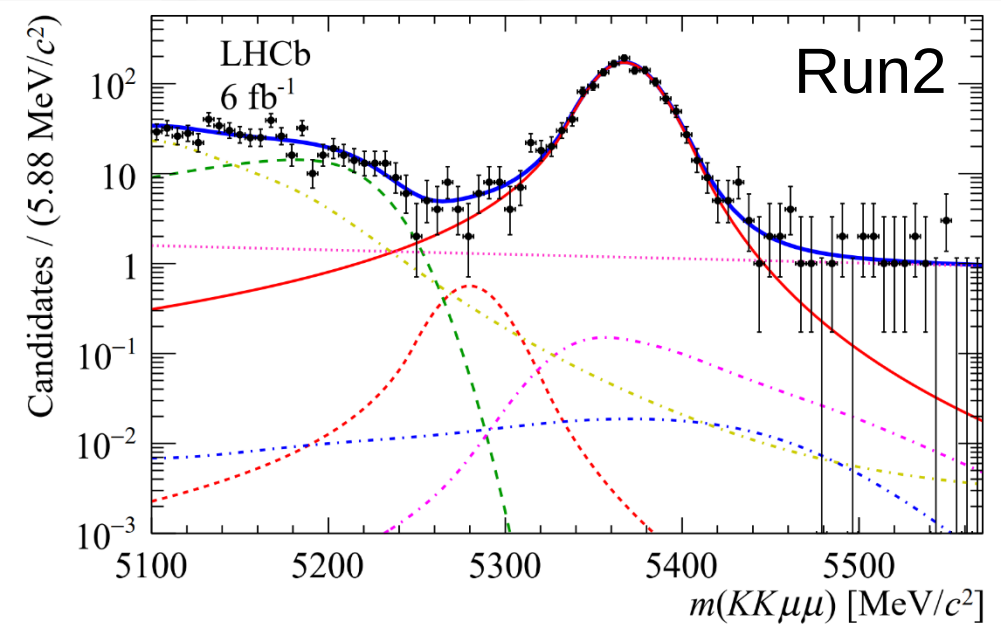




$B_s^0 \to \phi\mu^+\mu^-$

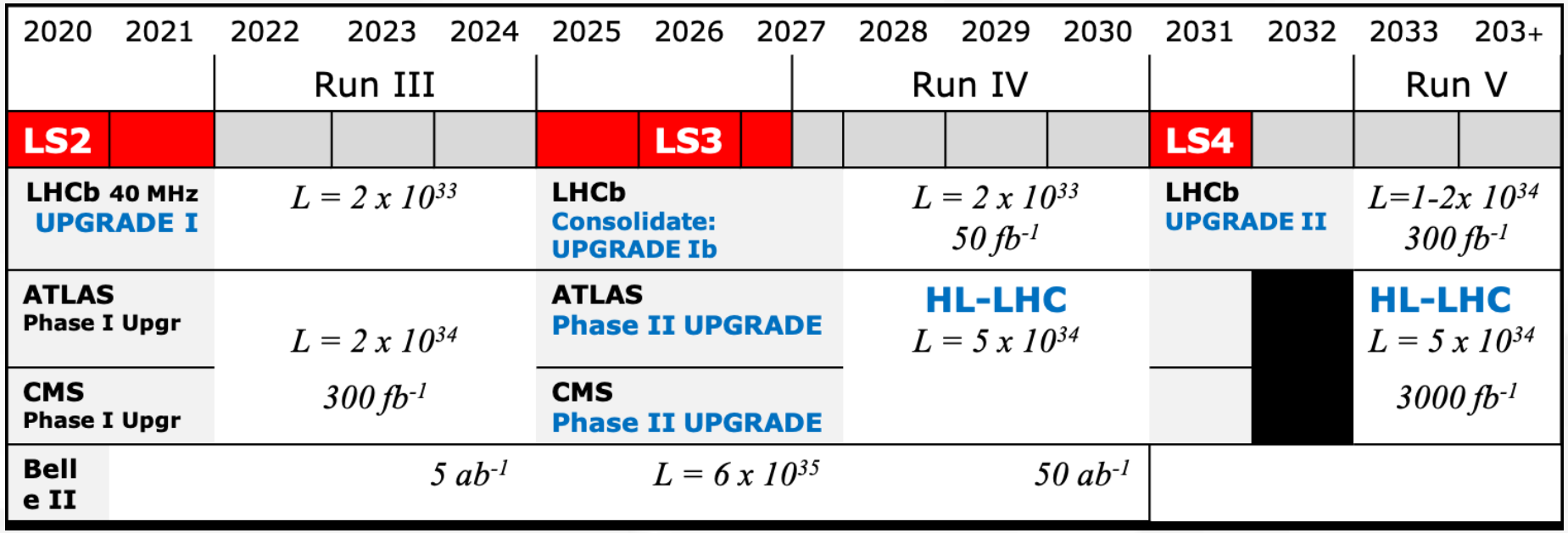
$B^0 \to \phi\mu^+\mu^-$

Conclusions

- Two-body or Four-body baryonic B decay:
  - Gives a tighter $\mathcal{B}(B_s^0 \to p\bar{p})$ upper limit
  - First observation of $B^0 \to p\bar{p}p\bar{p}$, and $\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p})$ is bigger than expected
- BNV and LNV decay:
  - No BNV and LNV observed in the decay $B_{(s)}^0 \to p\mu^-$, gives $\mathcal{B}\left(B_{(s)}^0 \to p\mu^-\right)$ upper limit
- Soft-collinear effective theory - sensitive:
  - Gives $\mathcal{B}(B^0 \to \phi\mu^+\mu^-)$ upper limit
  - Limited by sensitivity or by contributions from new physis
- Ongoing RD analysis:
  - LFU$(b \to sll)$: $R(K^{*0}), R(K\pi\pi), R(\phi)$…
  - Angular analysis: $\Lambda_b \to pK^-\mu^+\mu^-$, $B_s^0 \to \phi\mu^+\mu^-$…
  - CPV: $B_s^0 \to \phi\gamma$

Outlook

- Run3 4 times the integrated luminosity of Run2, it is expected to search more RD decay with better sensitivity



Thanks!