Purely leptonic rare decays at LHCb

Workshop on status and perspectives of physics at high intensity
9 - 11 November 2022
Laboratori Nazionali di Frascati

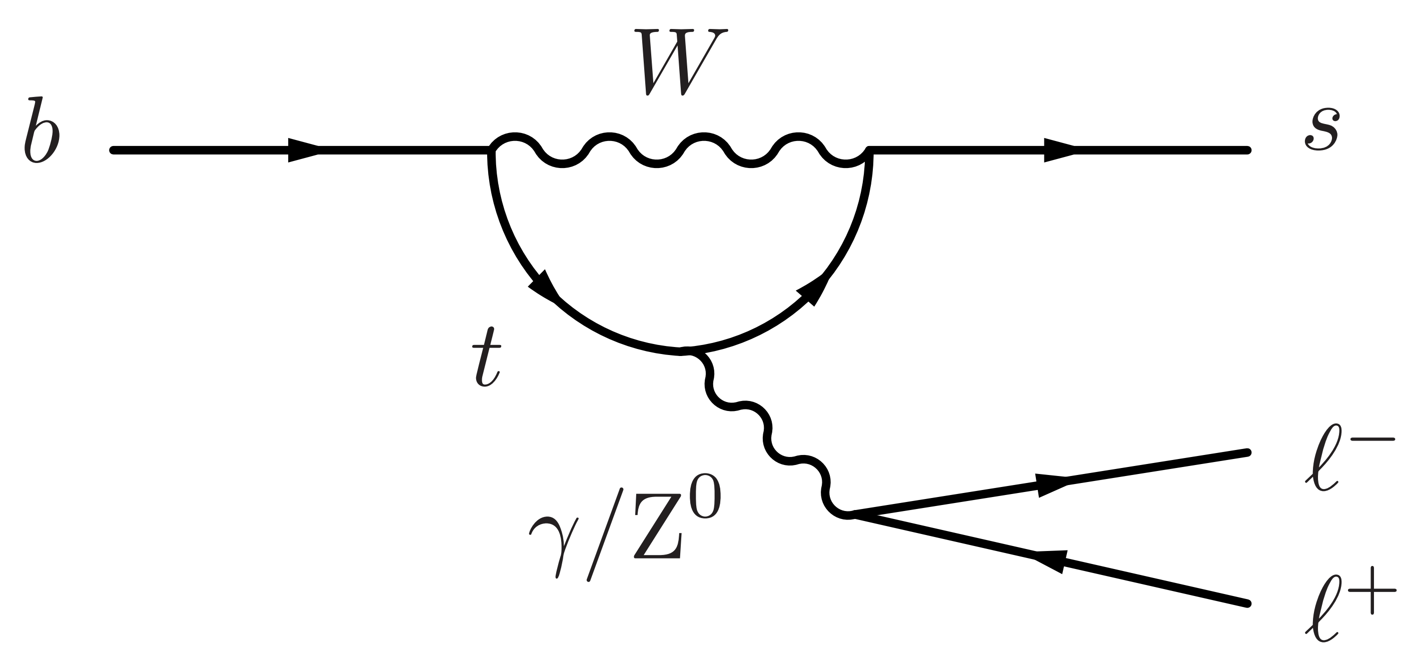
Flavio Archilli - Università di Roma "Tor Vergata"

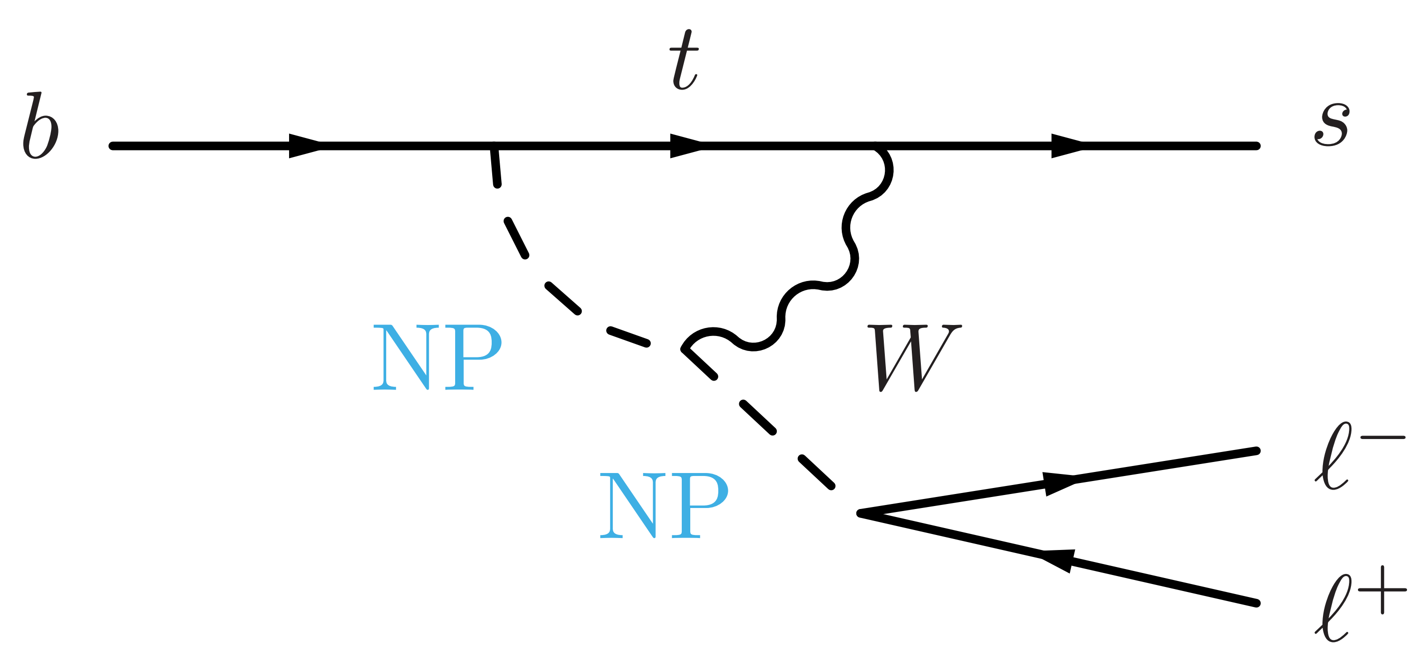
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

INFN

(No) introduction

- I hope somebody gave gave a short theoretical introduction before me!
- In the SM, FCNC processes are forbidden at the first order



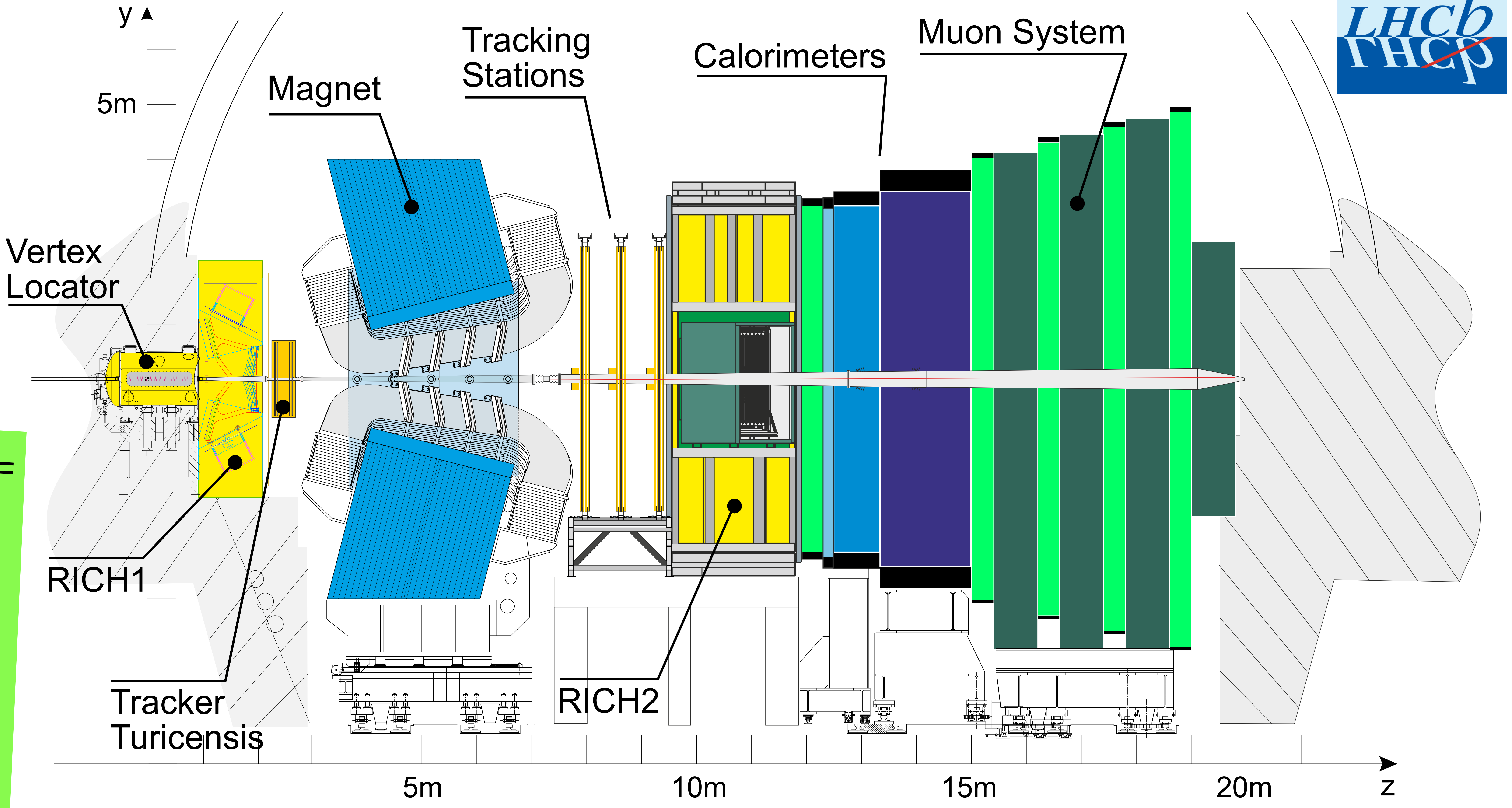


- New heavy Particles can significantly contribute and change the rates/ angular distribution/ asymmetries
- Purely-leptonic decays are typically
  - Rarer in the SM due to helicity suppression
  - Theoretically cleaner due to no hadrons in the final

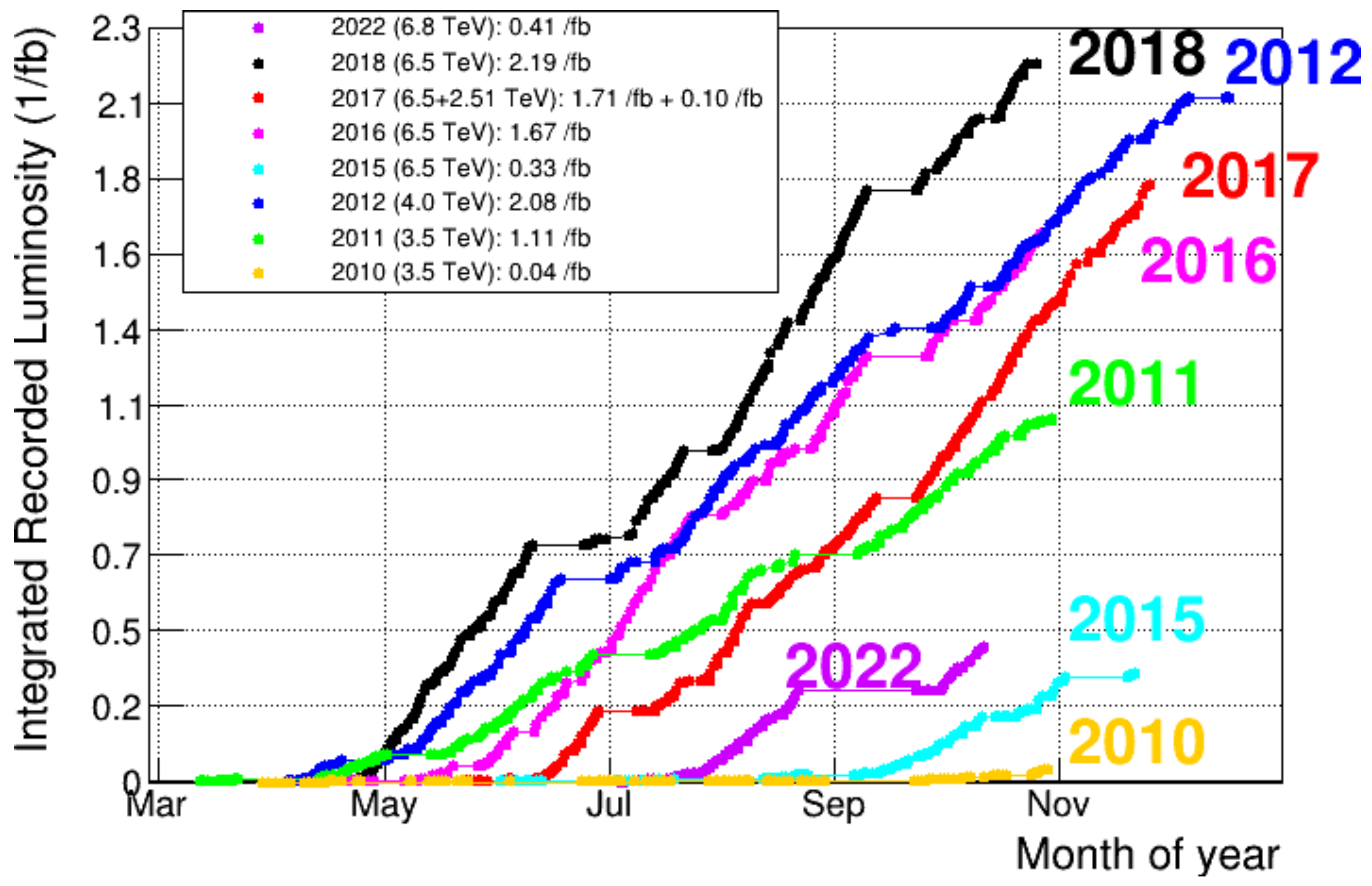
a glimpse of the LHCb detector

- Large $pp \to b\bar{b}X$ cross section
- $b\bar{b}$ produced at low angle $\to$ forward spectrometer
- b-hadrons produced with large boost $\to$ excellent vertex resolution for background reduction

- Excellent muon identification (ε_μ = 98%) and low misID $\varepsilon_{h\to\mu} \sim 0.5\%$
- High trigger efficiency on B decays with muons (ε_μ~90%)
- Well suited for $b \to s\ell\ell$ analyses



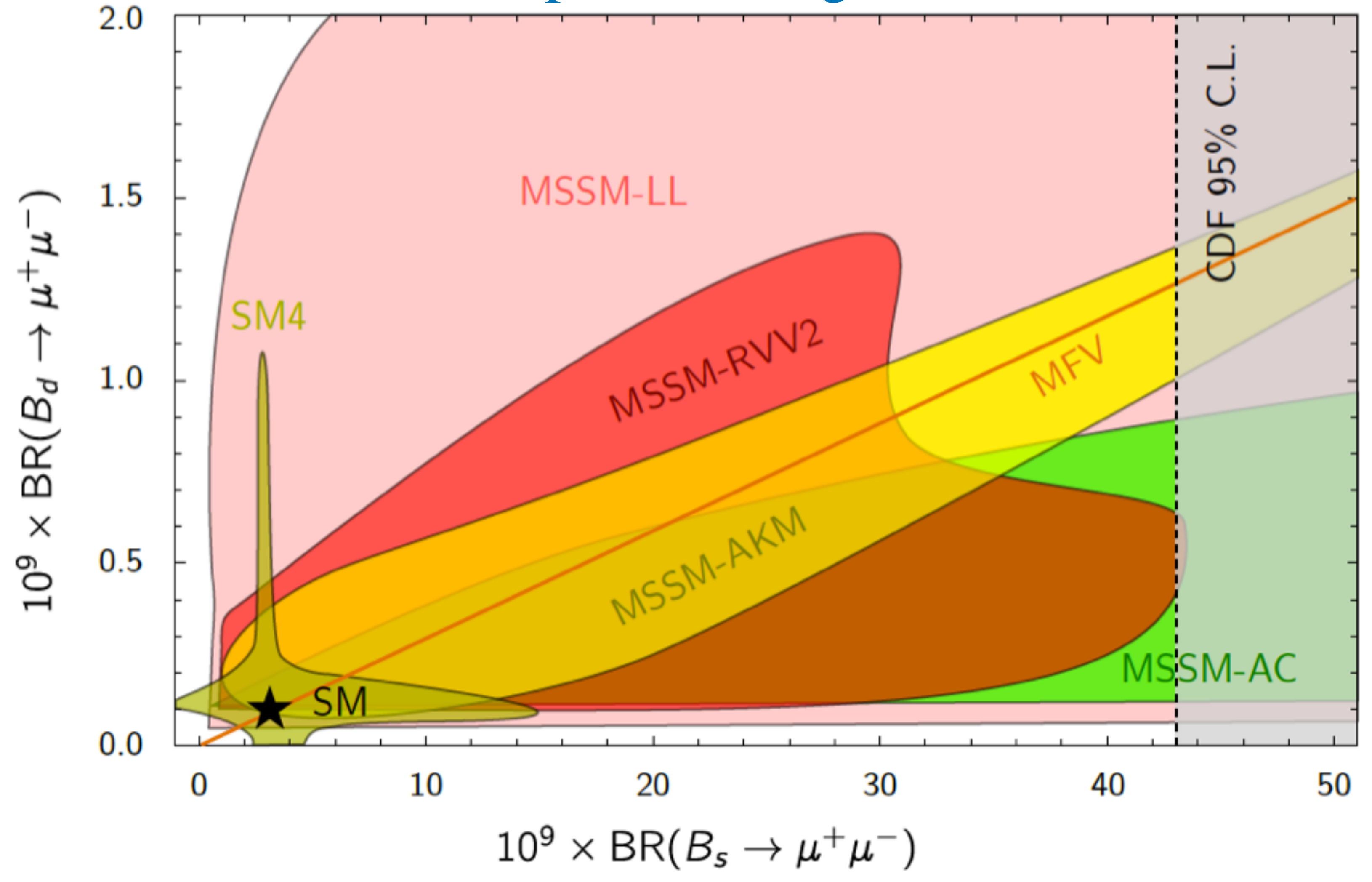
Datasets and schedule



- LHCb already collected 9 fb^{-1} during Run1+2
- Upgrade I is already here with an improved detector: 40MHz readout/software trigger and new tracking → integrated luminosity expected $\sim 50\ \text{fb}^{-1}$
- Upgrade II will allow to collect 300 fb^{-1} (Run5) [CERN-LHCC-2021-012][CERN-LHCC-2018-027]

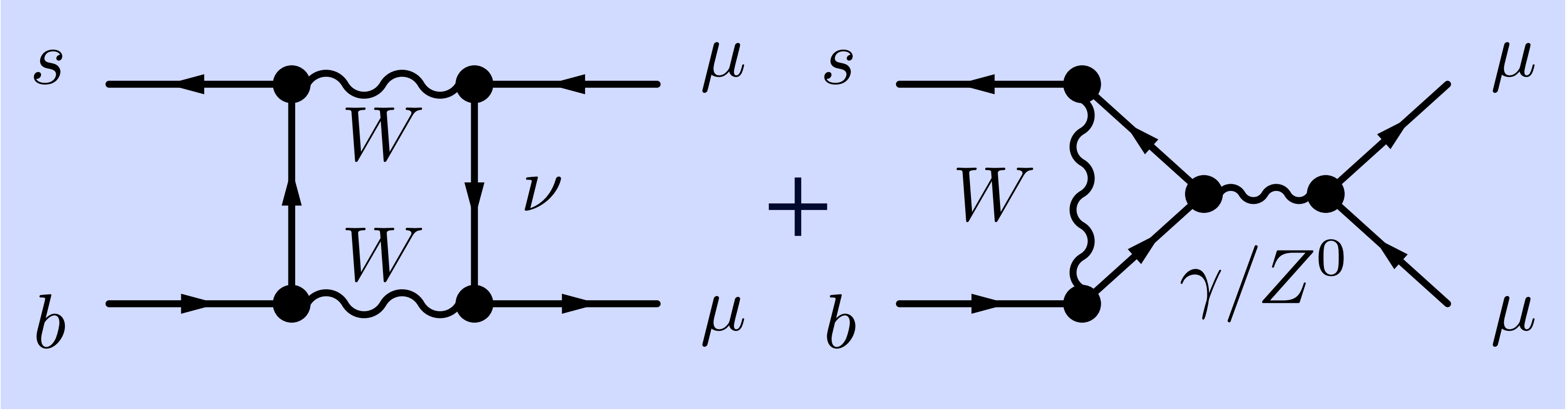
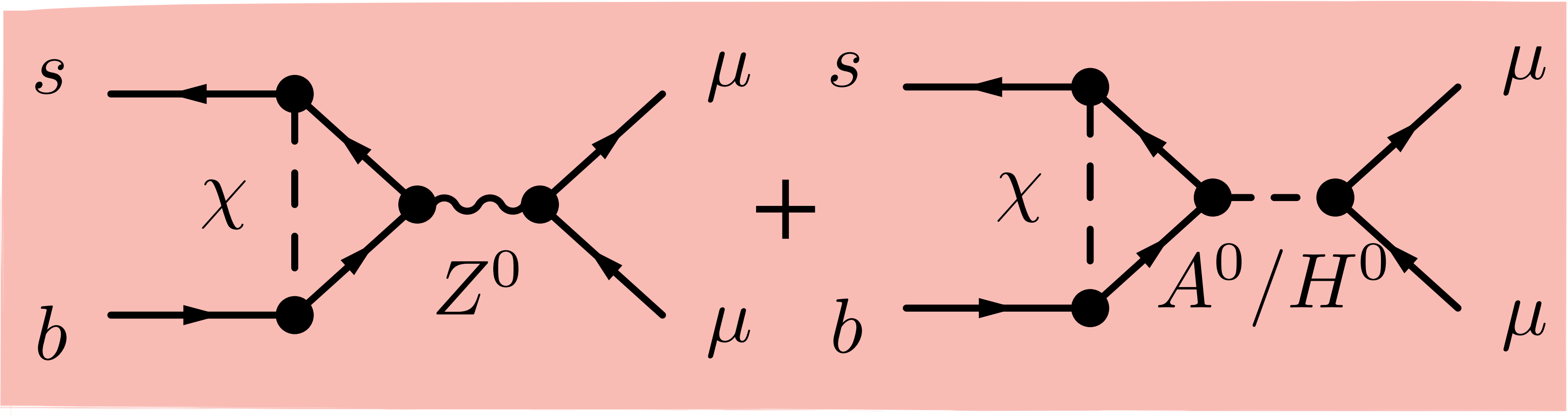
Purely leptonic decay: $B^0_{(s)} \to \mu^+\mu^-$

http://arxiv.org/abs/1205.6094



- $B^0_{(s)} \to \mu^+\mu^-$ is a golden channel for LHCb:
  - CKM suppressed, loop suppressed and helicity suppressed
  - Powerful probe of models with new enhanced (pseudo) scalar interactions, e.g SUSY at high $\tan(\beta)$ ($\mathscr{B} \propto \tan(\beta)^6/m_A^4$)

$$\mathscr{B} = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 m_{B_s}^3 |V_{tb}V_{tq}|^2 \tau_{B_s} \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} \left[(1 - \frac{4m_\mu^2}{M_B^2}) |C_S - C_S'|^2 + |(C_P - C_P') + \frac{2m_\mu}{M_B}(C_{10} - C_{10}')|^2 \right]$$

$\mathscr{B} \propto \text{const} \times \Big|$  +  $\Big|^2$

SM **NP**

- Branching fraction predicted precisely in the SM:

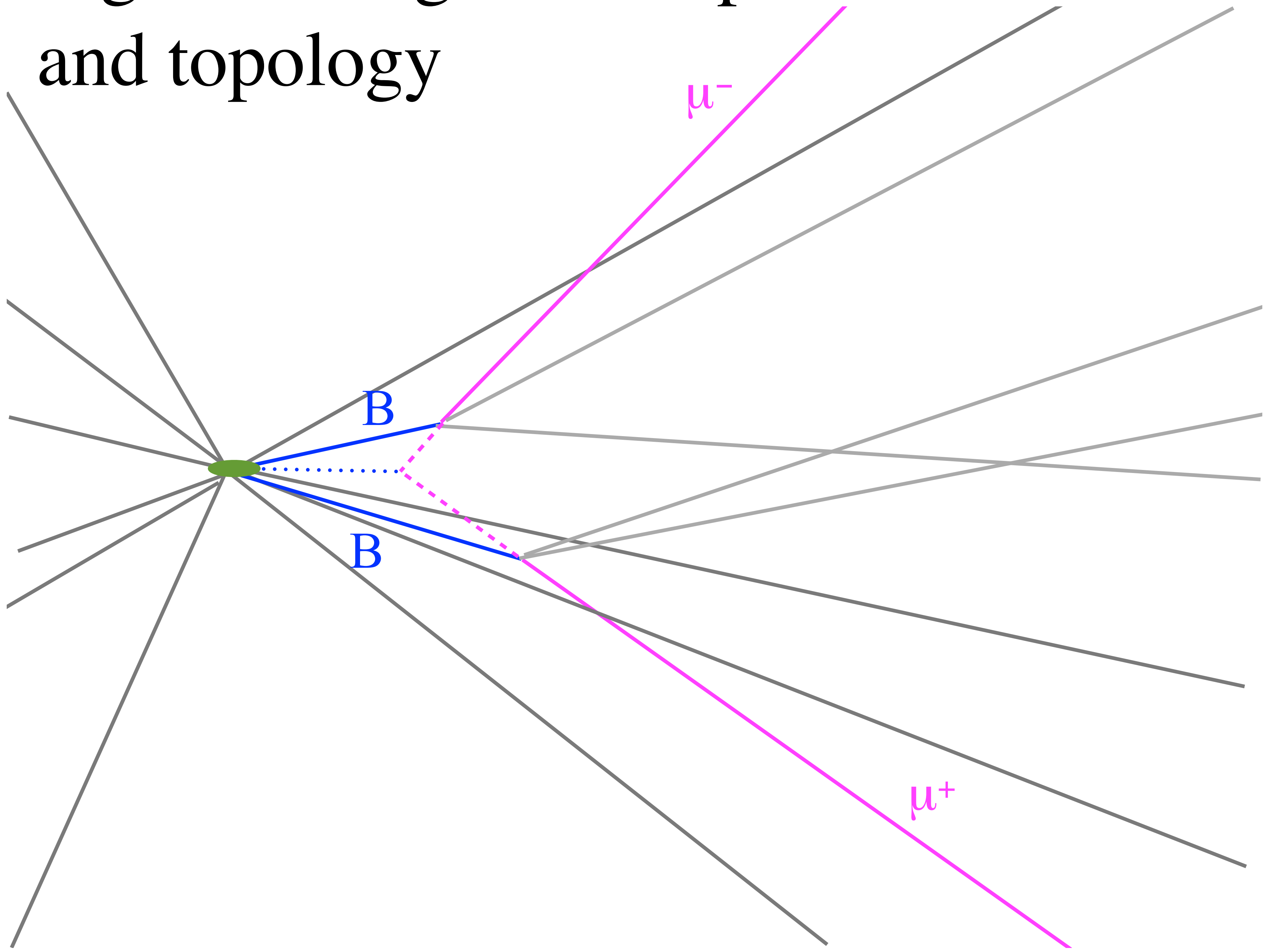
$$\mathscr{B}(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.14) \times 10^{-9}$$
$$\mathscr{B}(B^0 \to \mu^+\mu^-) = (1.03 \pm 0.05) \times 10^{-10}$$

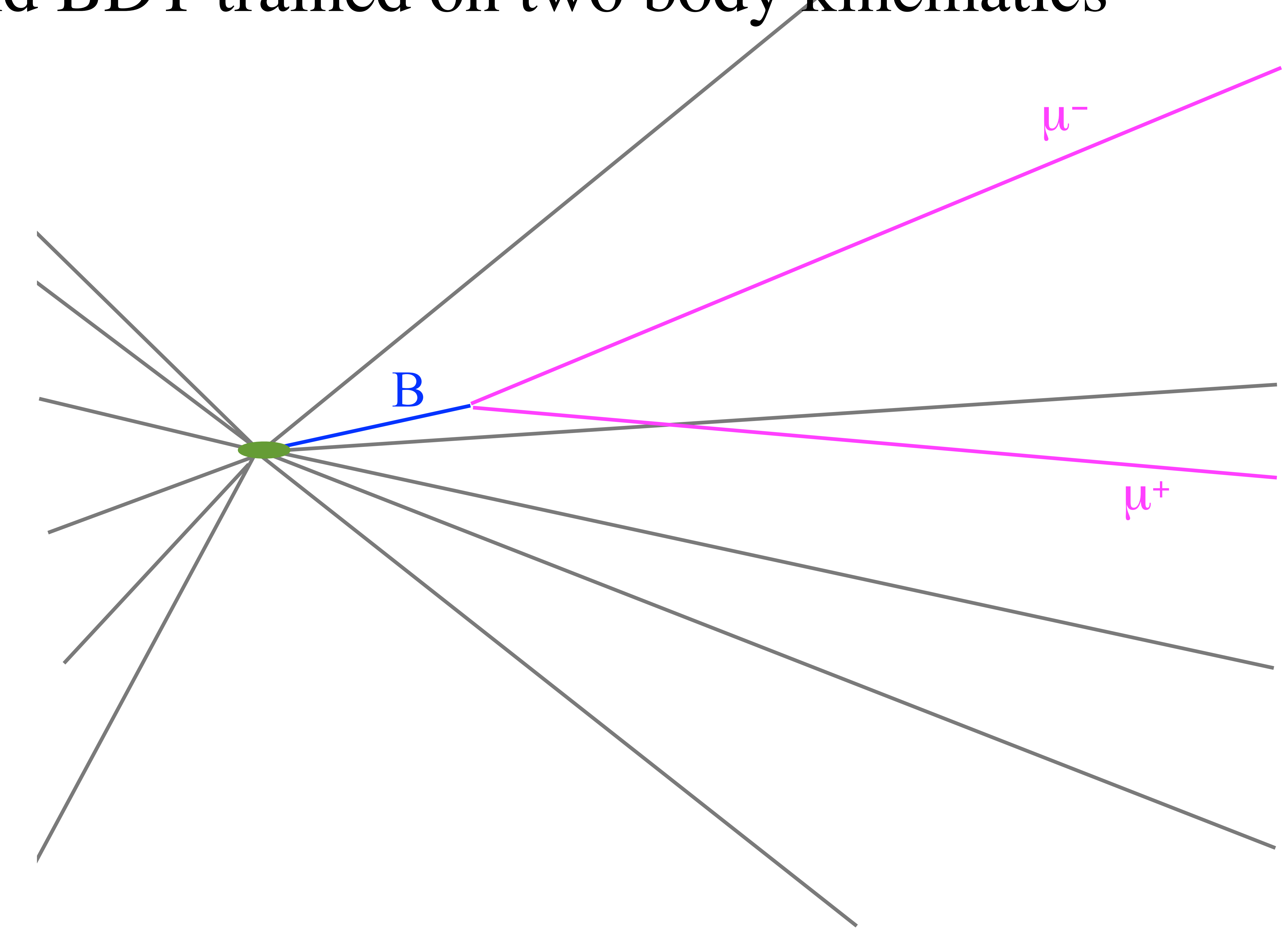
[JHEP10(2019)232]

Main uncertainties from CKM element and decay constant f_{B_s} from Lattice QCD

$B^0_{(s)} \to \mu^+\mu^-$ Analysis strategy

- Blind analysis on Run1+Run2 data set (9 fb^{-1})
- Main background due to combinatorics of two μ's.
- Signal/Background separation obtained through $m_{\mu\mu}$ and BDT trained on two body kinematics and topology





[Phys. Rev. Lett. 128, (2022) 041801]
[Phys. Rev. D105 (2022) 012010]

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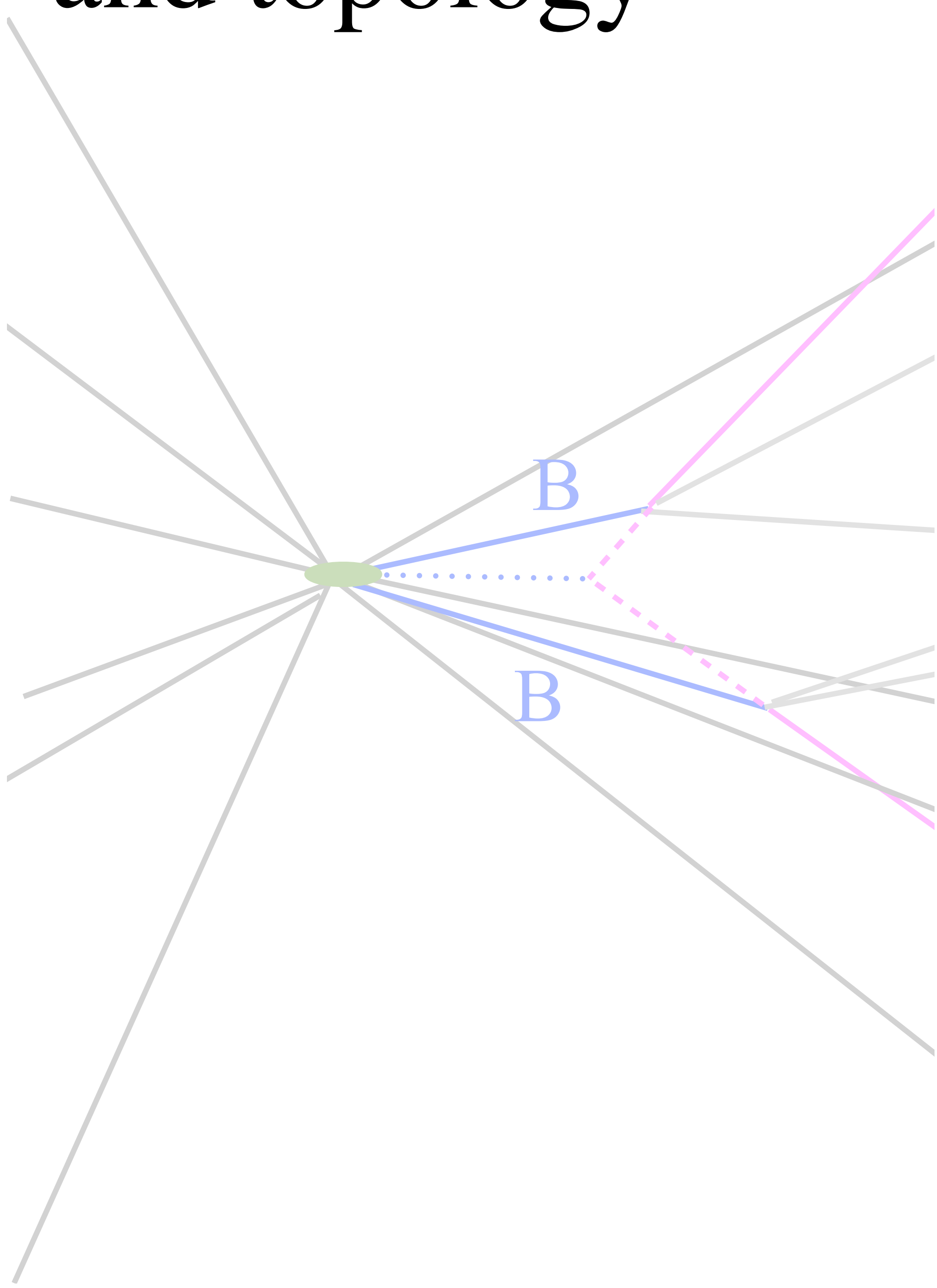
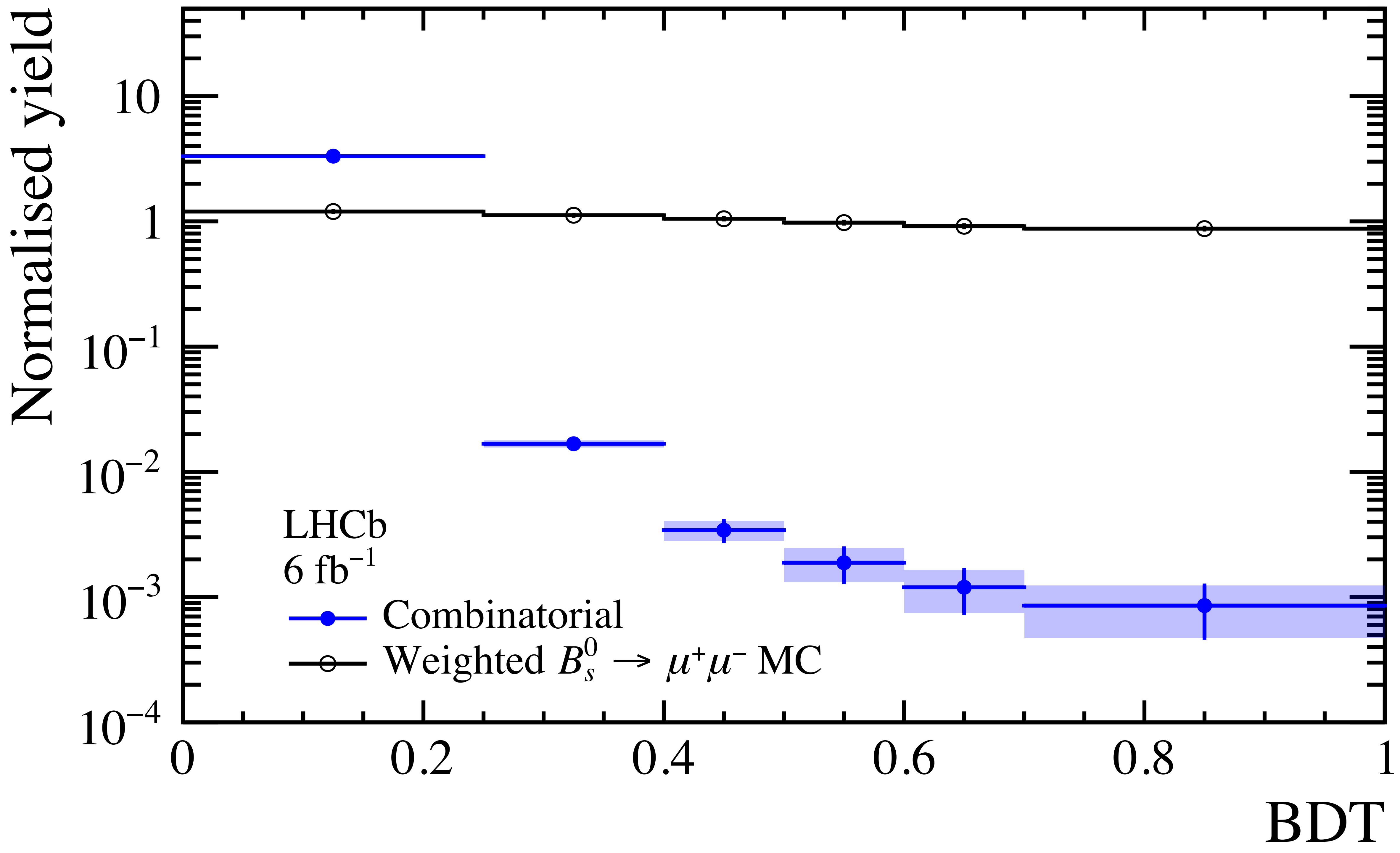
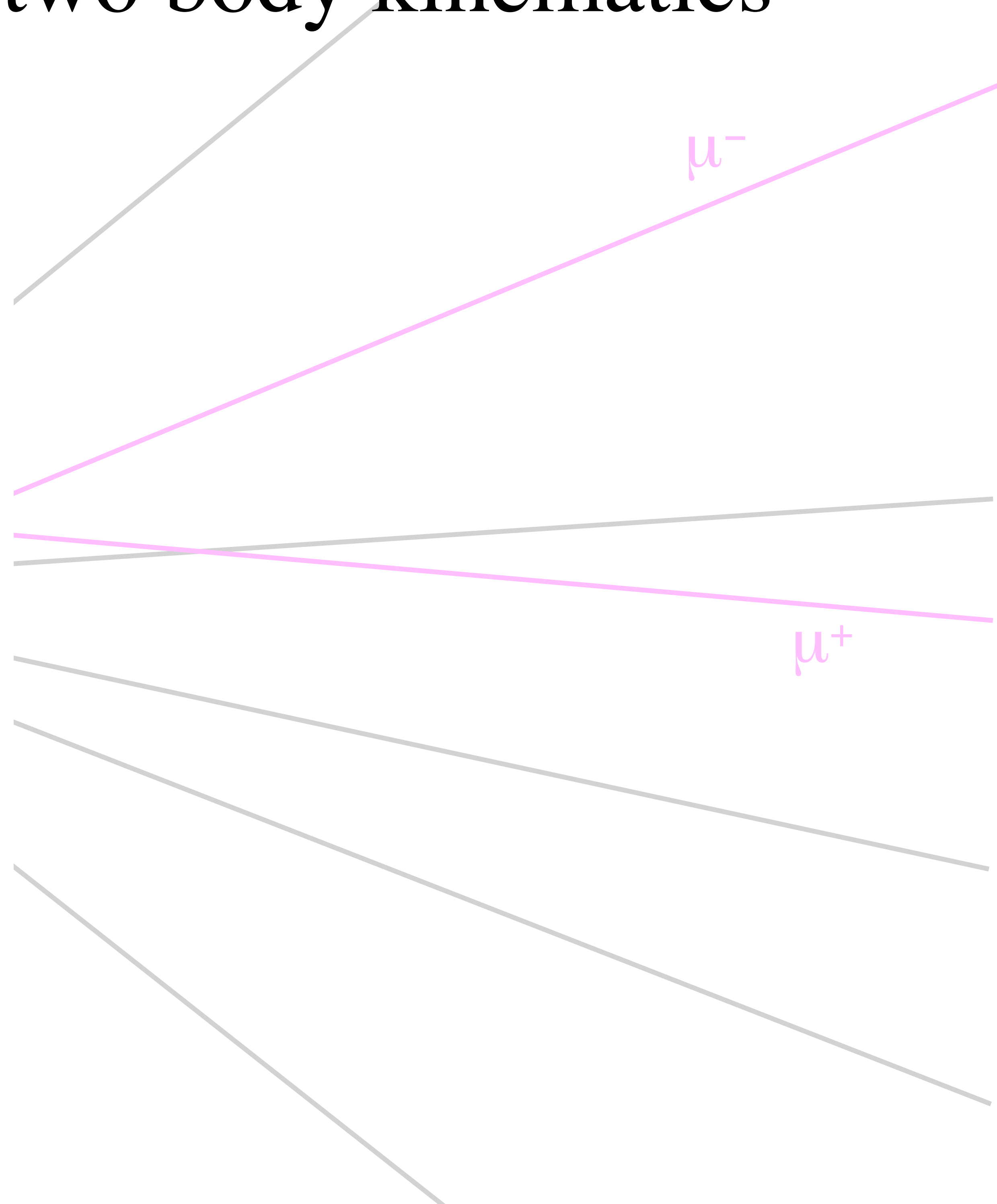




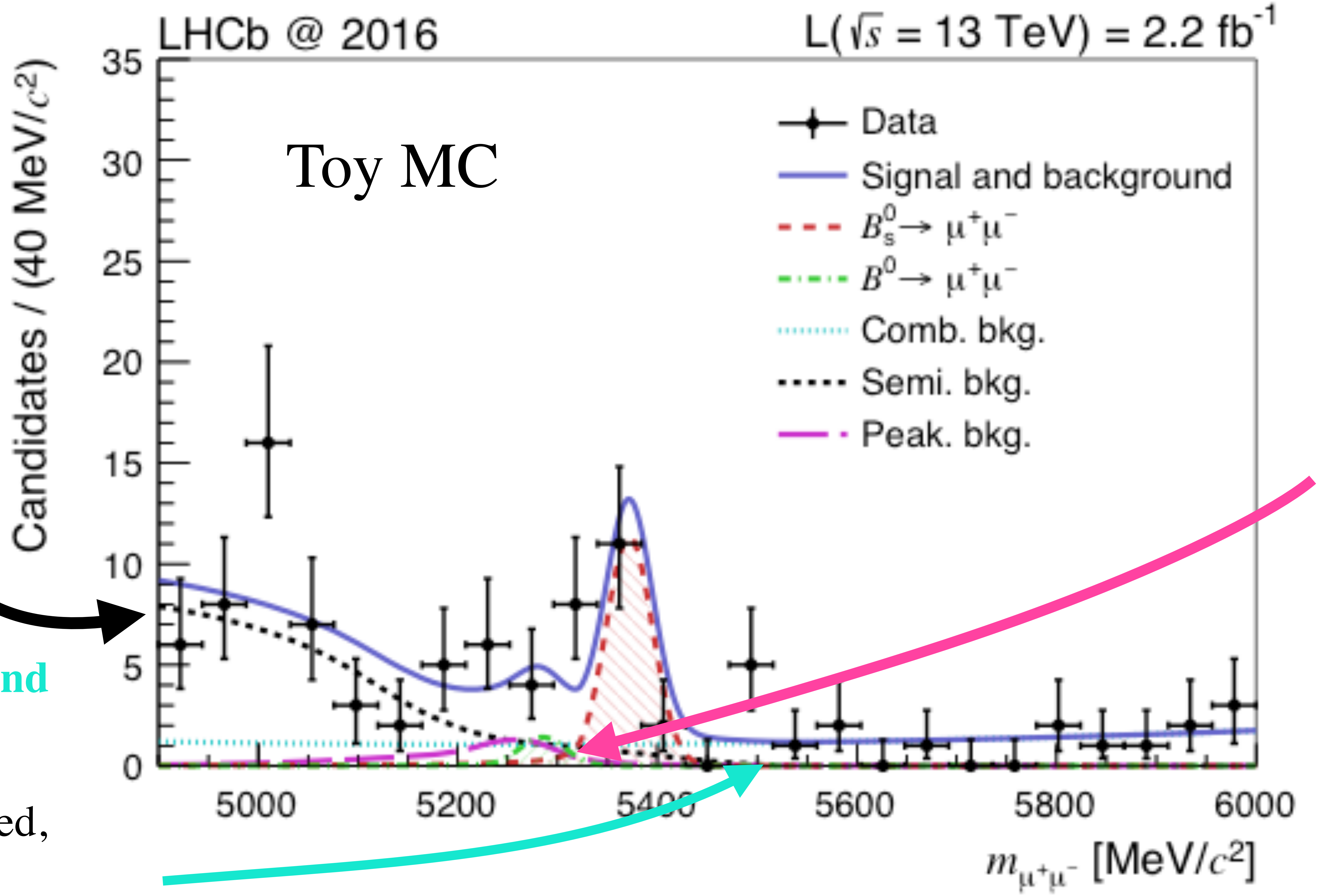


$B^0_{(s)} \to \mu^+\mu^-$ peaking background

- The most sensitive region is polluted by both combinatorial background and exclusive channels $B^0_{(s)} \to h^+h^{'-}$

Semileptonic decays

eventually with one hadron misidentified as muon:estimated with large samples of MC, and normalising to $B^\pm \to J/\psi K^\pm$

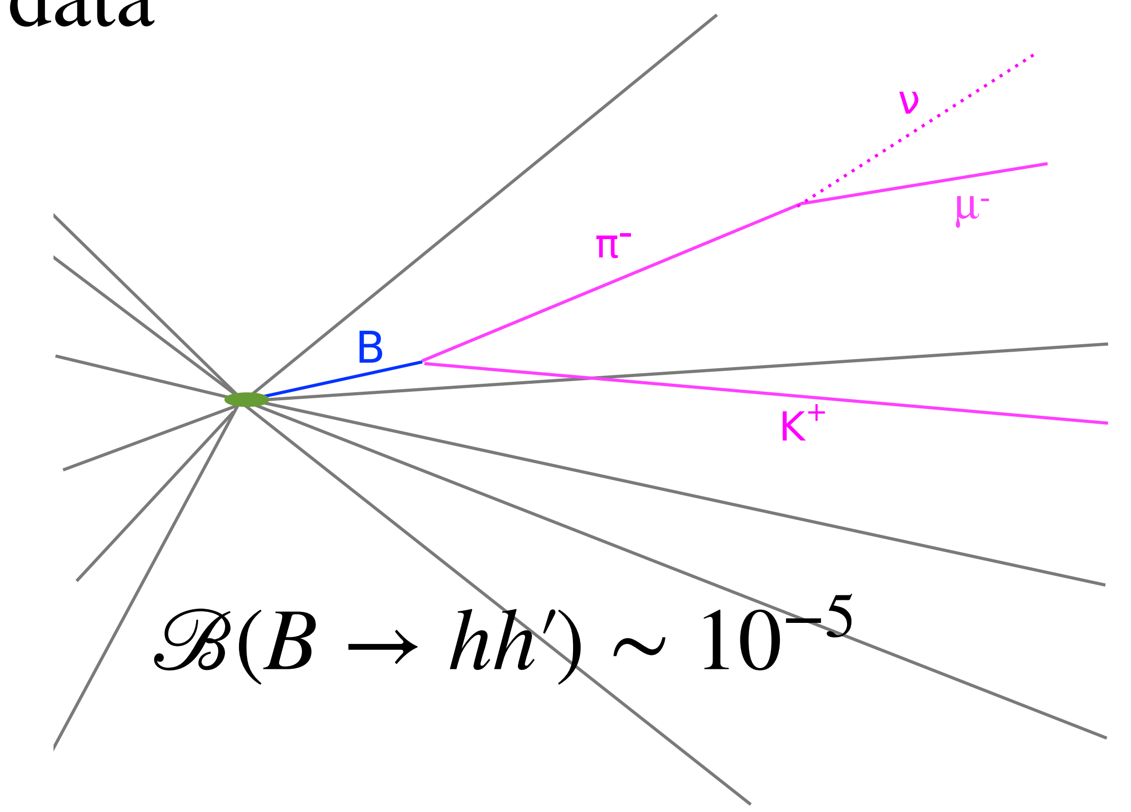


Combinatorial background

from $b\bar{b} \to \mu^+\mu^- X$:
an exponential shape is used, the normalisation is a free parameter of the invariant mass fit

$B^0_{(s)} \to h^+h^{'-}$ decays (h=K,π)

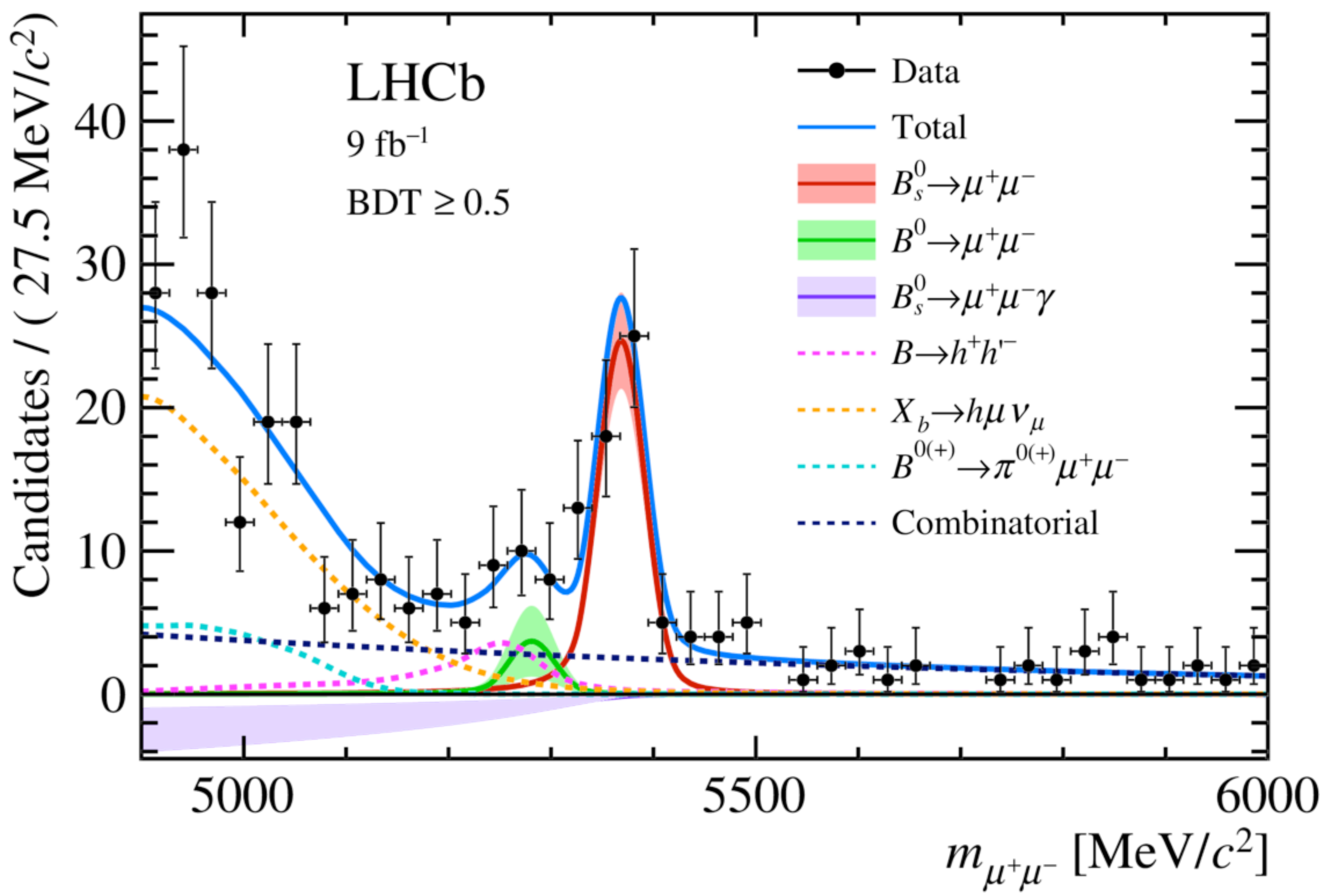
both hadrons misidentified as muons (prob~2x10^{-5}): this background peaks in the B^0 signal region; it is estimated from not misidentified events, and using PID efficiencies from data

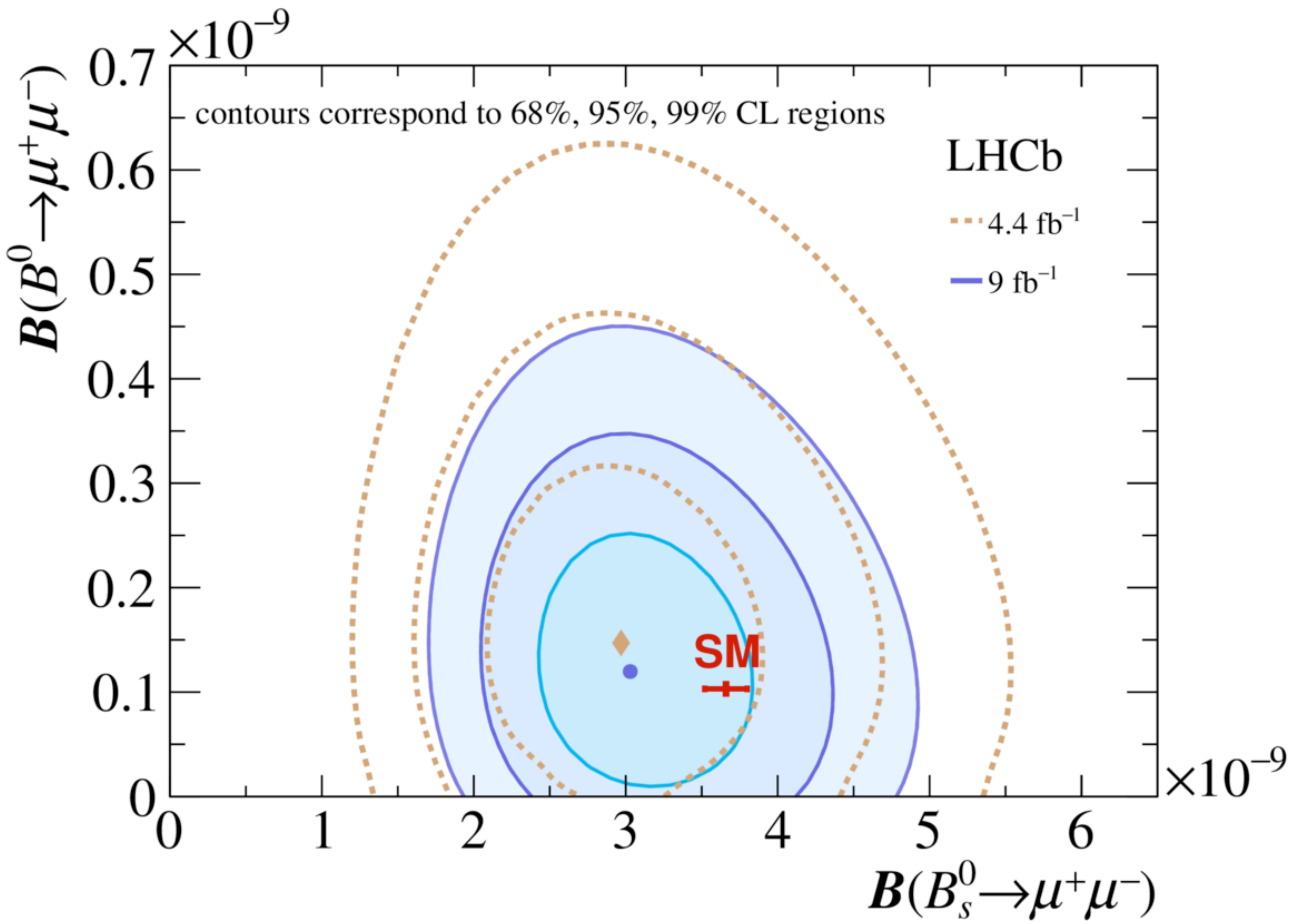


$\mathscr{B}(B \to hh') \sim 10^{-5}$

LHCb Results

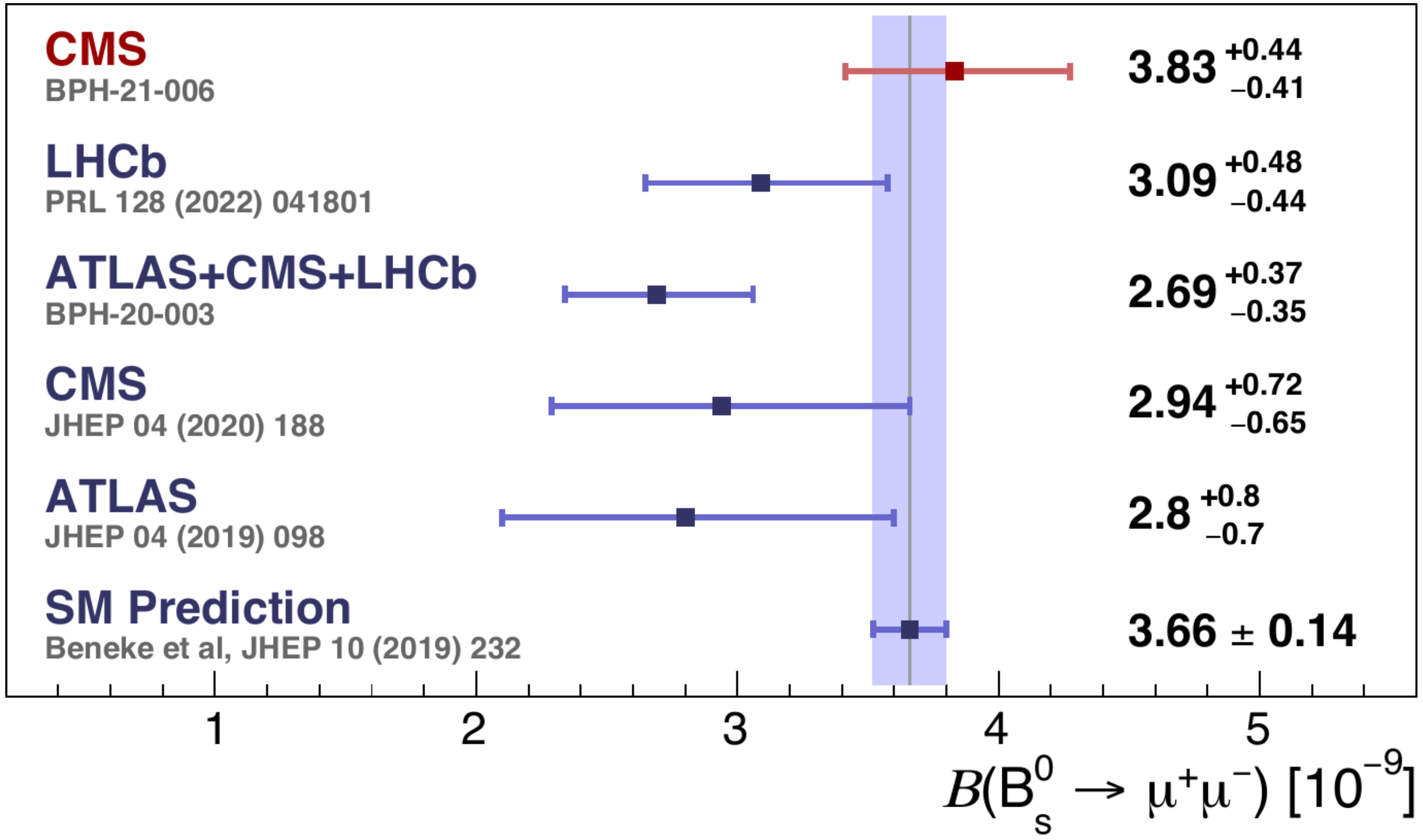
[Phys. Rev. Lett. 128, (2022) 041801]
[Phys. Rev. D105 (2022) 012010]

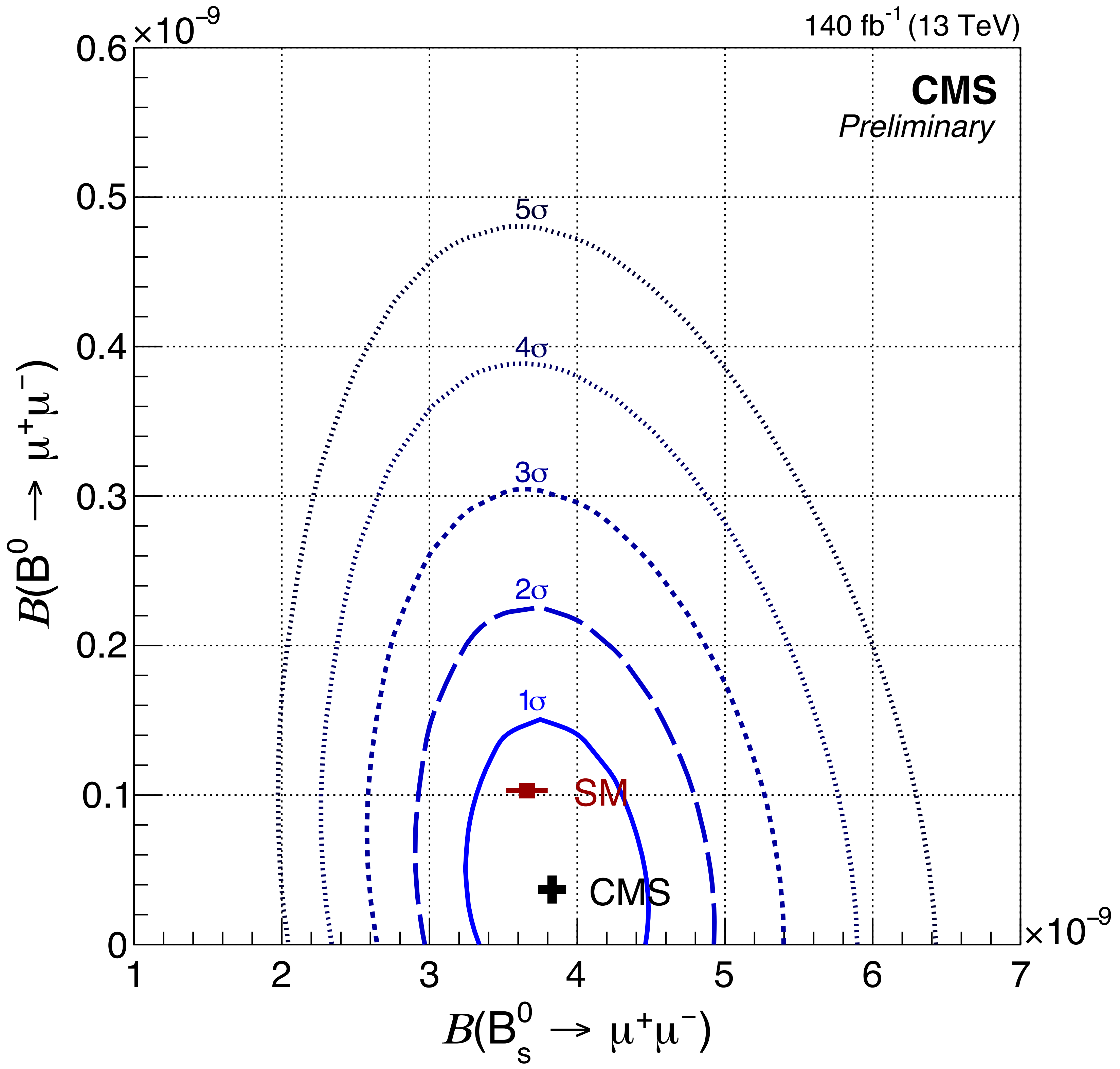




- Simultaneous fits to the bins of multivariate response to determine B^0 and B_s^0 branching fractions
- Signal normalised to $B^+ \to J/\psi K^+$ and $B^0 \to K^+\pi^-$
- $\mathscr{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}\right) \times 10^{-9}$
- $\mathscr{B}(B^0 \to \mu^+\mu^-) = (1.2^{+0.8}_{-0.7} \pm 0.1) \times 10^{-10}$ $\quad$ ($\mathscr{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$ at 95 % CL)

CMS results





- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.83^{+0.38}_{-0.36}(\text{stat})^{+0.19}_{-0.16}(\text{syst})^{+0.14}_{-0.13}(f_s/f_u)\right) \times 10^{-9}$
- $\mathcal{B}(B^0 \to \mu^+\mu^-) = (0.37^{+0.75}_{-0.67}{}^{+0.08}_{-0.09}) \times 10^{-10} \quad \left(\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.9 \times 10^{-10} \text{ at } 95\,\%\,\text{CL}\right)$

LHCb impact on theory

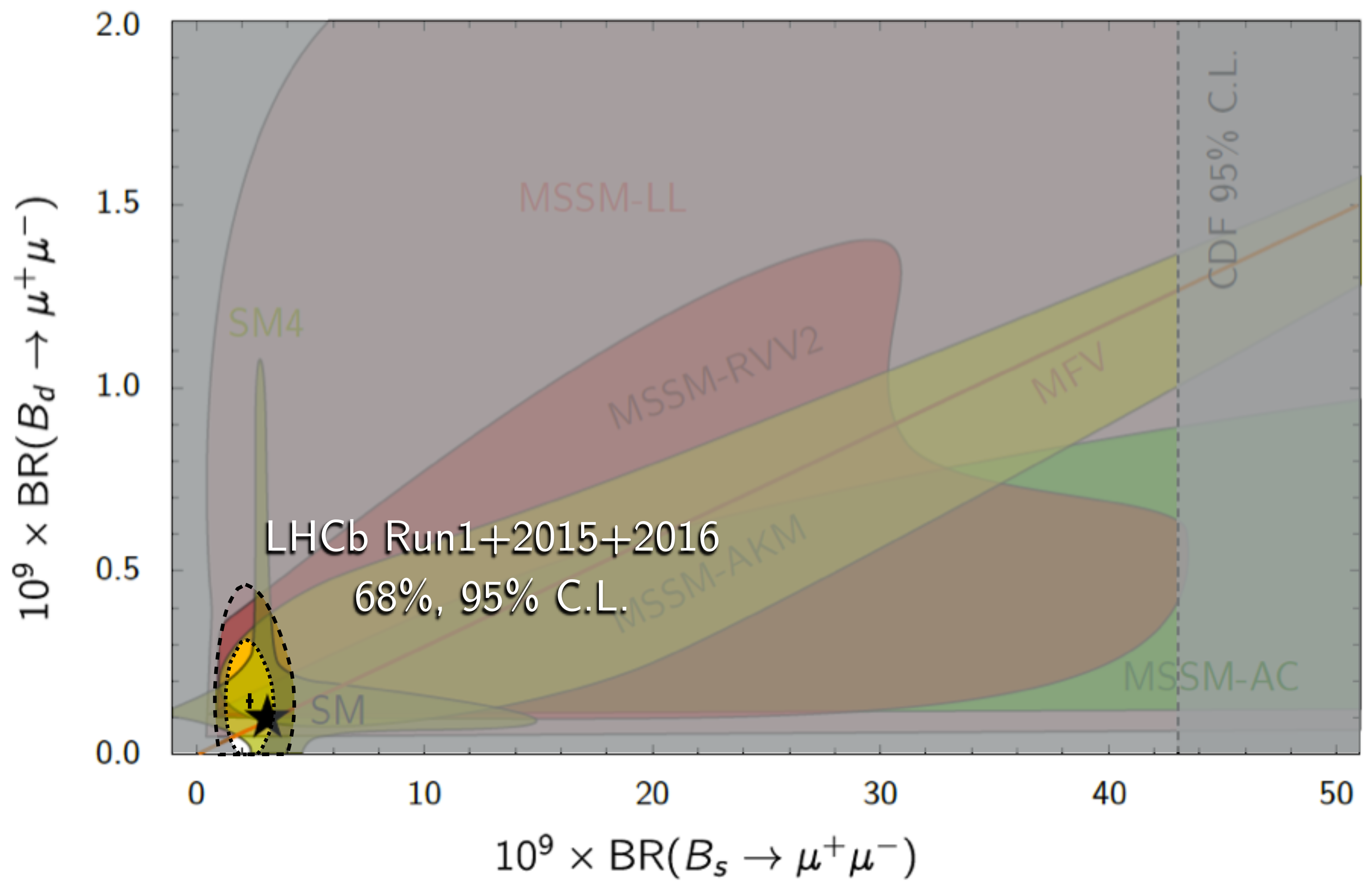
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ is an important probe of supersymmetric extension of SM

- Current LHCb analysis performances: ~16% uncertainty on $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$

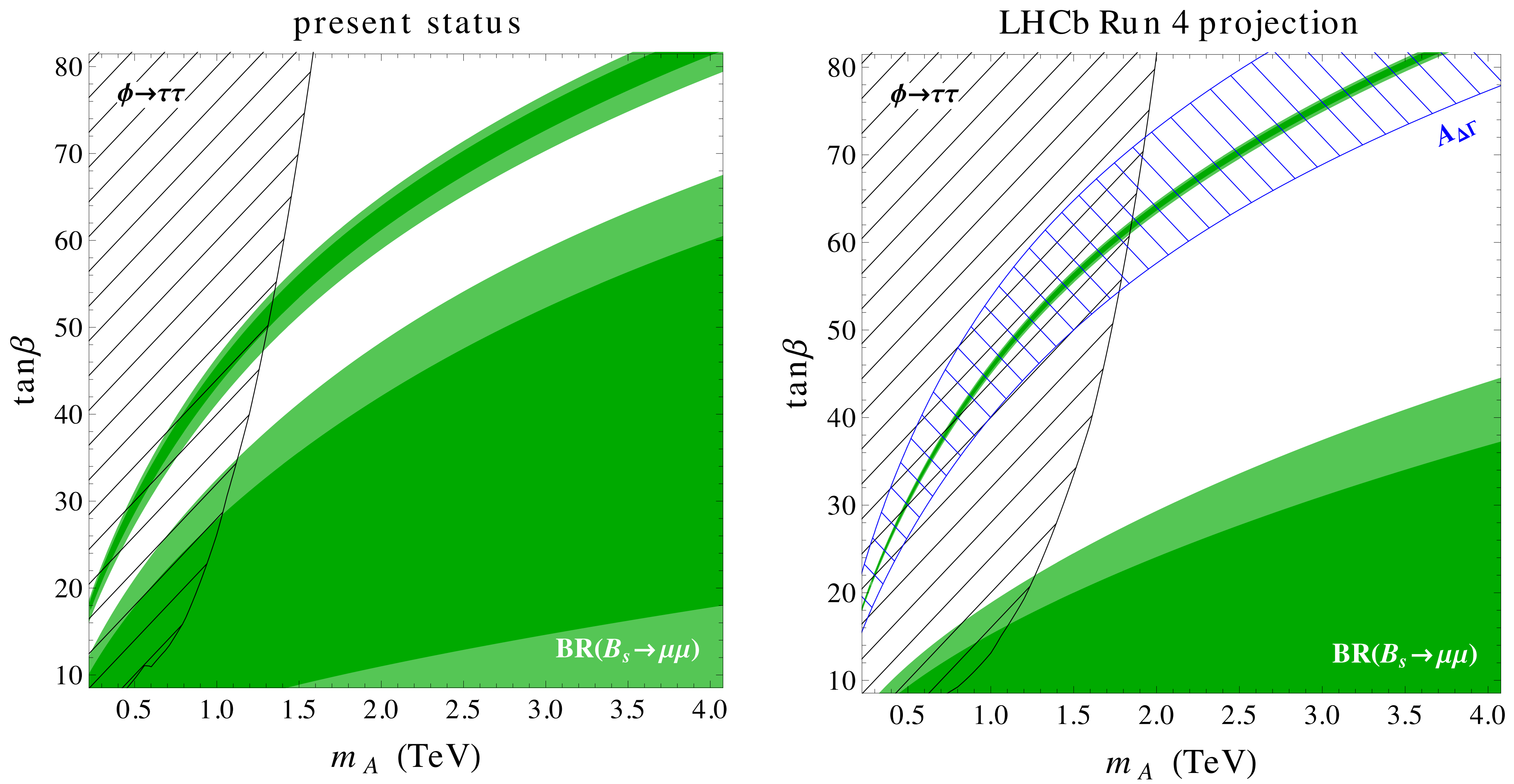
- Combination with ATLAS and CMS will push $\Delta\mathcal{B}/\mathcal{B}$ below 7% which is the expected uncertainty at the end of Run4 for LHCb only

- Complementary to direct searches of MSSM with $\tau\tau$ resonances

http://arxiv.org/abs/1205.6094



JHEP05(2017)076



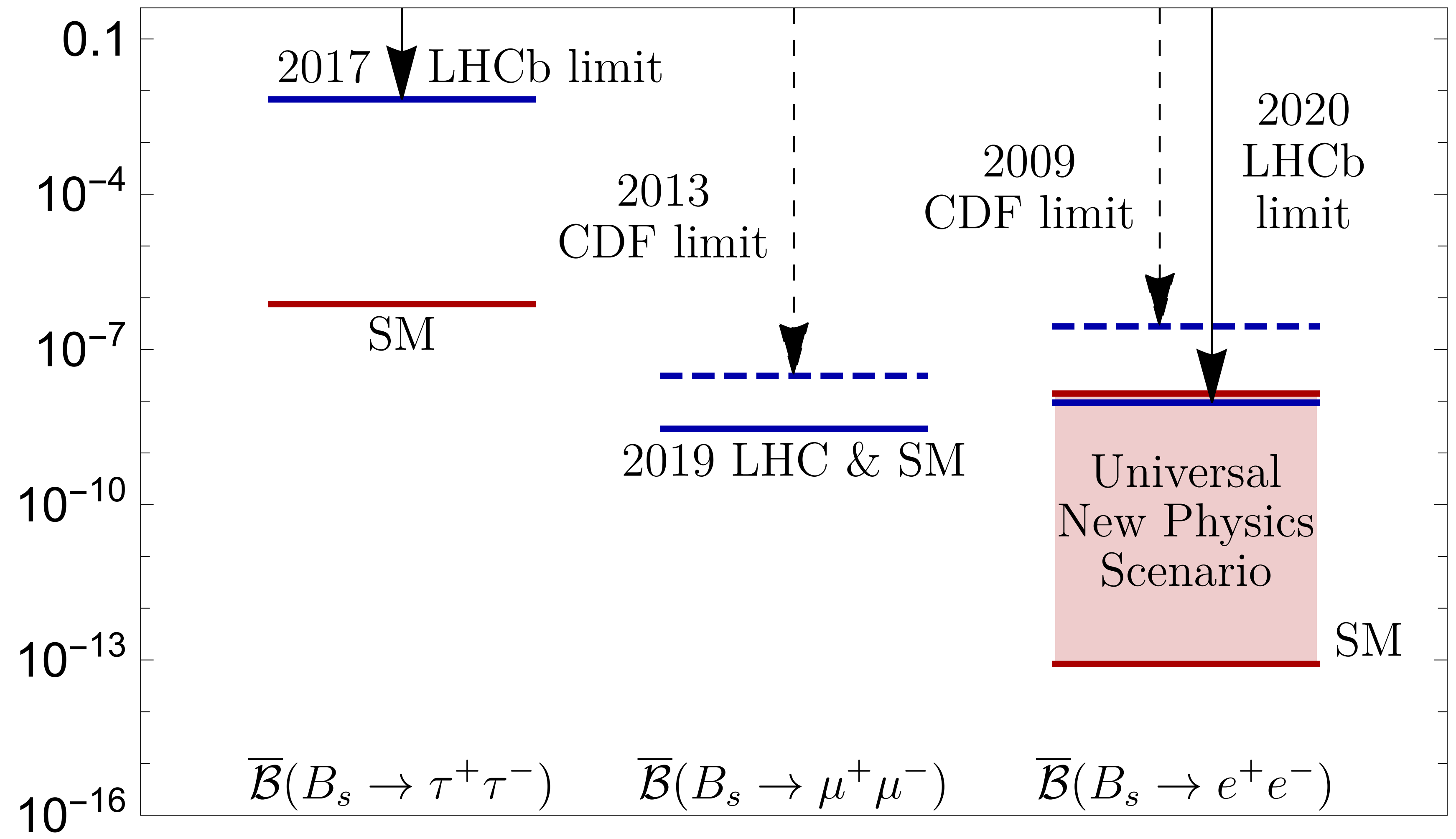
Test of LFU with $B^0_{(s)} \to e^+e^-$ decays

- Helicity suppressed by $\mathcal{O}(10^{-4})$ relative to $B^0_{(s)} \to \mu^+\mu^-$
- $\mathcal{B}(B^0_s \to e^+e^-) = (8.35 \pm 0.39) \times 10^{-14}$
- $\mathcal{B}(B^0 \to e^+e^-) = (2.39 \pm 0.14) \times 10^{-15}$

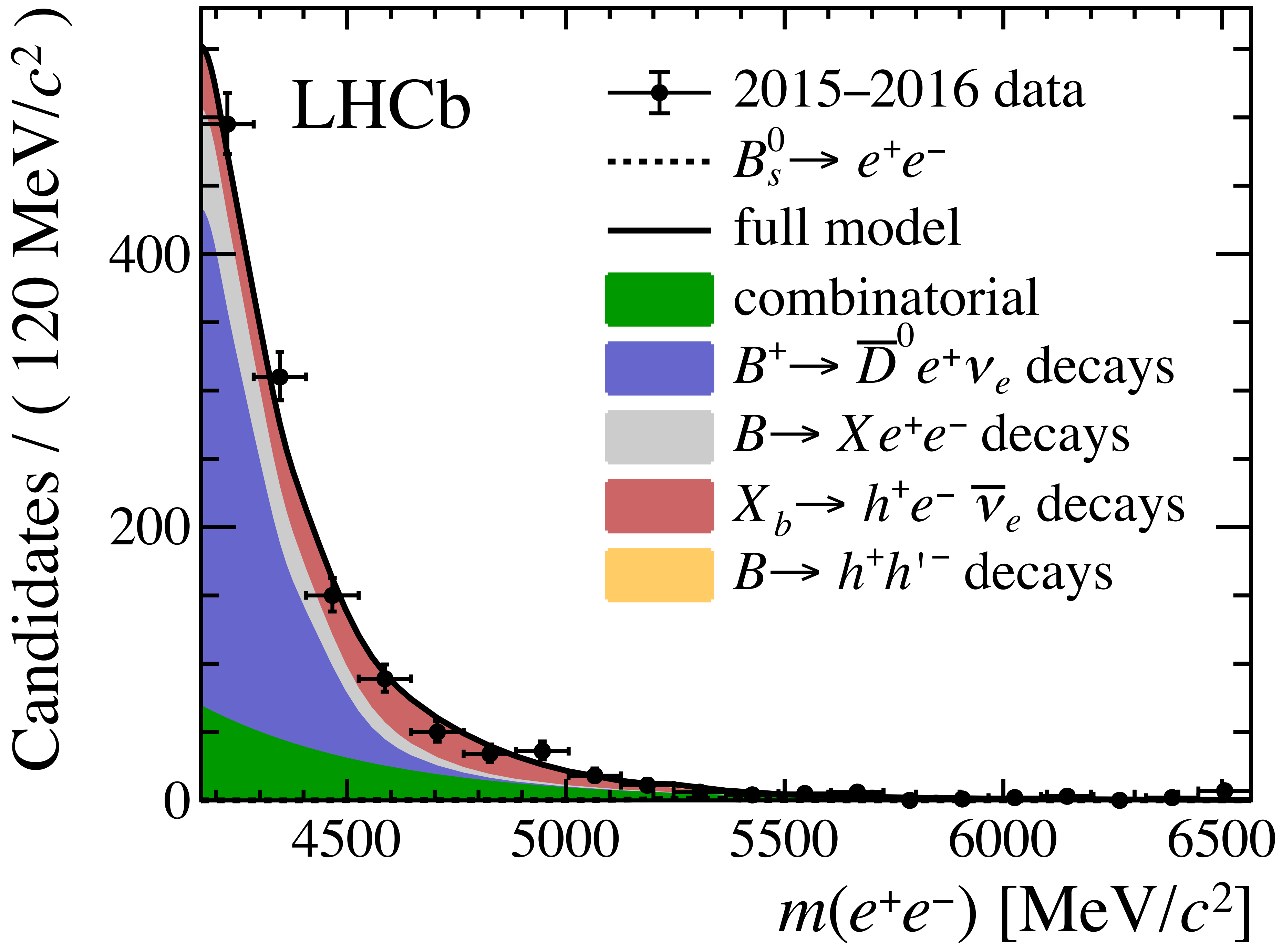
M. Beneke et al. JHEP 10 (2019) 232

- NP effects could increase BFs by $\mathcal{O}(10^6)$
- Current analysis performed on Run1+2015+2016 data
- Signal extracted from UML fit on $m_{e^+e^-}$
  - $\mathcal{B}(B^0_s \to e^+e^-) < 11.2 \times 10^{-9}$ at 95 % CL
  - $\mathcal{B}(B^0 \to e^+e^-) < 3.0 \times 10^{-9}$ at 95 % CL

Fleischer et al., JHEP 05 (2017) 156

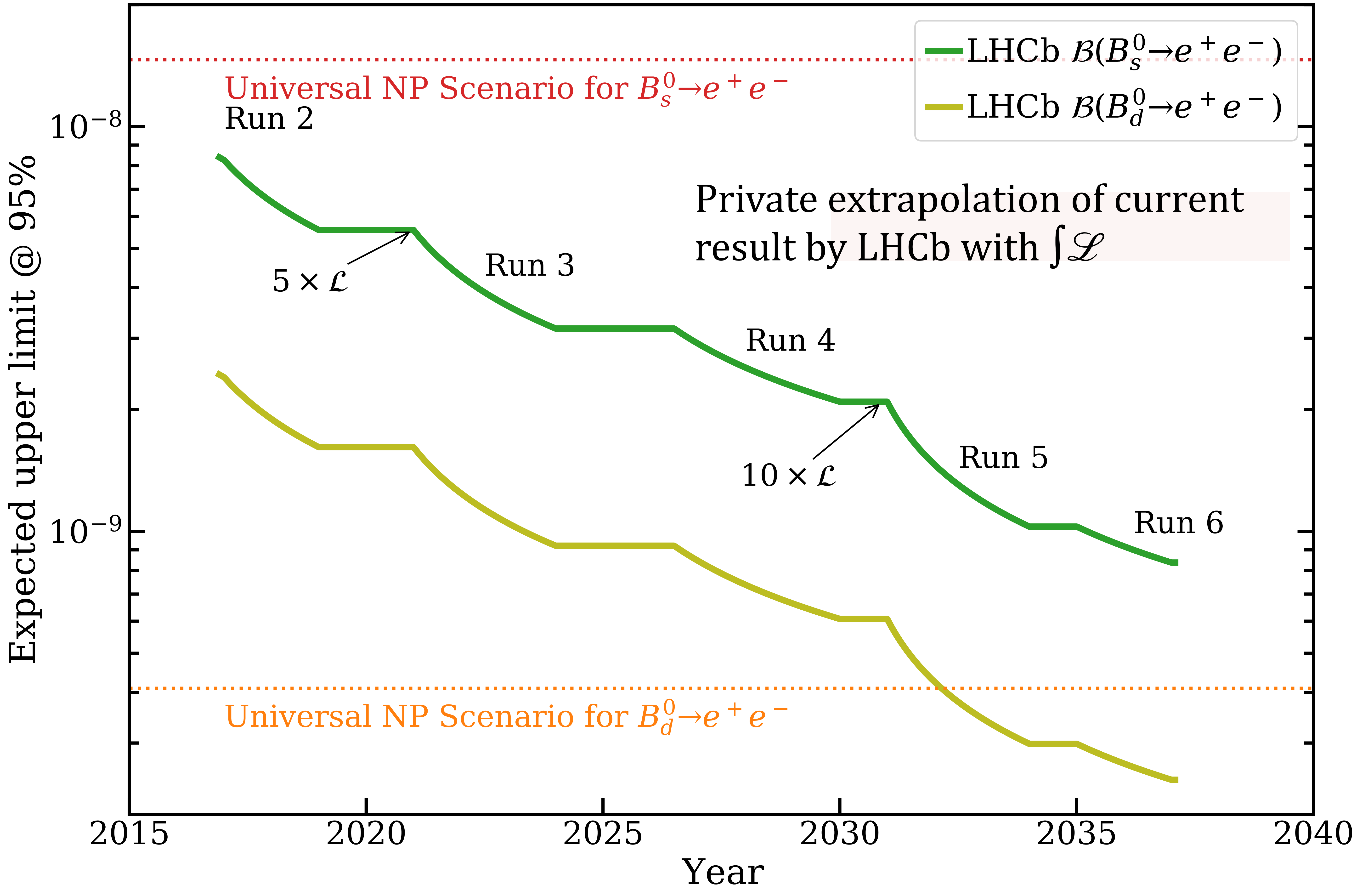


Phys. Rev. Lett. 124 (2020) 211802



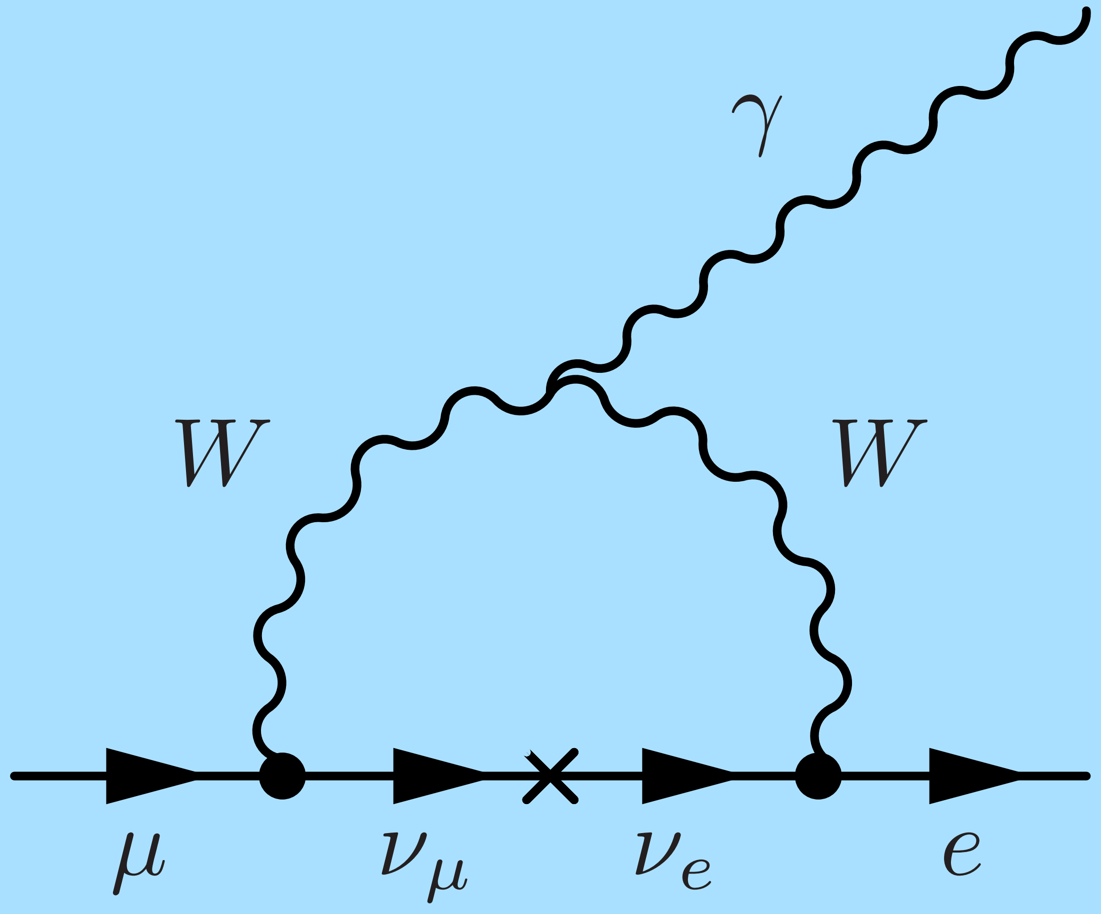
Prospects

- $B_s^0 \to e^+e^-$ already probing possible LUV scenarios
- Potential backgrounds like $B_s^0 \to e^+e^-\gamma$ might become relevant with larger statistics
- Electron reconstruction/PID unknown after UpgradeII
- Also $B_{(s)}^0 \to \tau^+\tau^-$ even if far from SM expectations still powerful tool to constraint NP Leptoquark models
  Phys. Rev. D 94, 115021 (2016)
- Run1: $\mathscr{B}(B_{(s)}^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3}$ @ 95 % CL
- 300 fb–1: $\mathscr{B}(B_{(s)}^0 \to \tau^+\tau^-) < 2.6 - 5 \times 10^{-4}$ @ 95 % CL



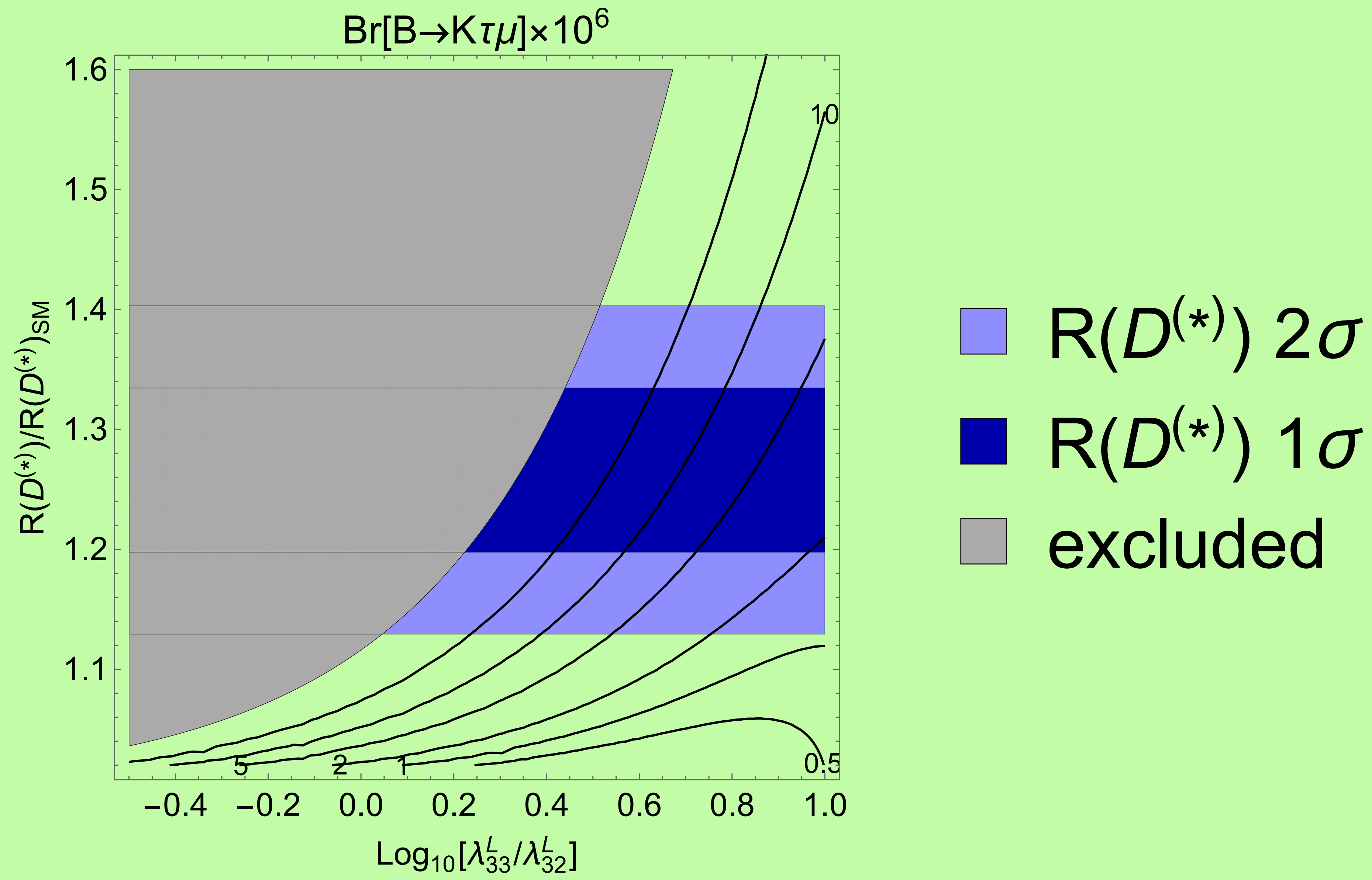
Lepton flavour violations measurements

- Lepton Flavour Violation forbidden in the SM
- Observation of neutrino oscillation → evidence of LFV in the neutral sector. However no observation of LFV in the charged sector so far



$$\mathscr{B}(\mu \to e\gamma) < 10^{-50}$$

- If LFUV confirmed



➡Interesting correlation with $b \to s\tau\mu$ and $b \to s\mu e$ LFV processes in several BSM models

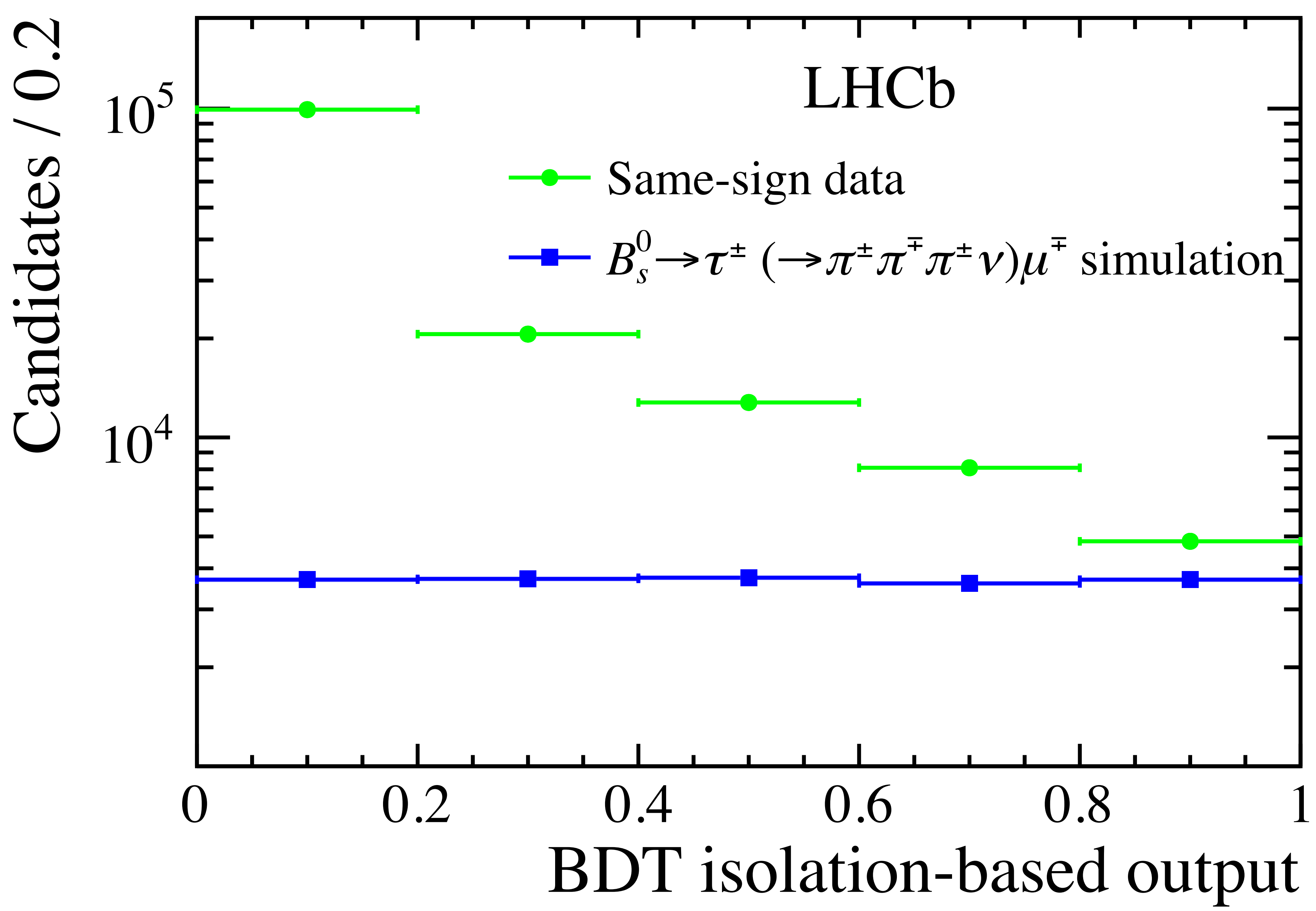
Crivellin, Mueller, Ota JHEP09(2017)040

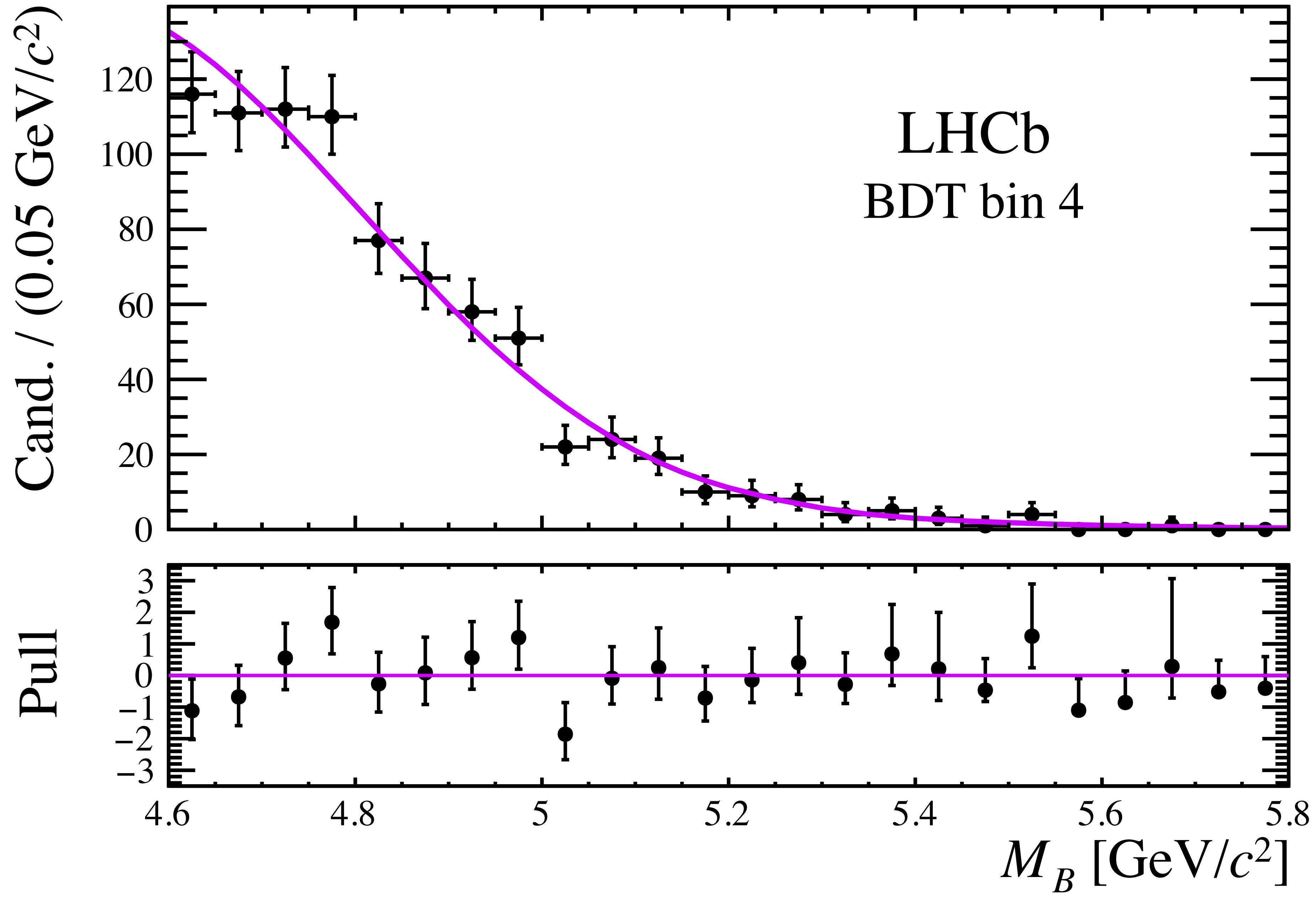
$B^0_{(s)} \to \tau^\pm \mu^\mp$

Phys. Rev. Lett. 123 (2019) 211801

- BF can be ~O(10^{-5}) in some models with Z'/ leptoquarks [JHEP 11 (2016) 035]
- LHCb analysis with Run1 data (3 fb^{-1})
- Reconstruct $B^0_{(s)} \to \tau^\pm \mu^\mp$ candidates using the 3-prong τ decays
- Events classified with multivariate operator and invariant mass (kinematically constrained)

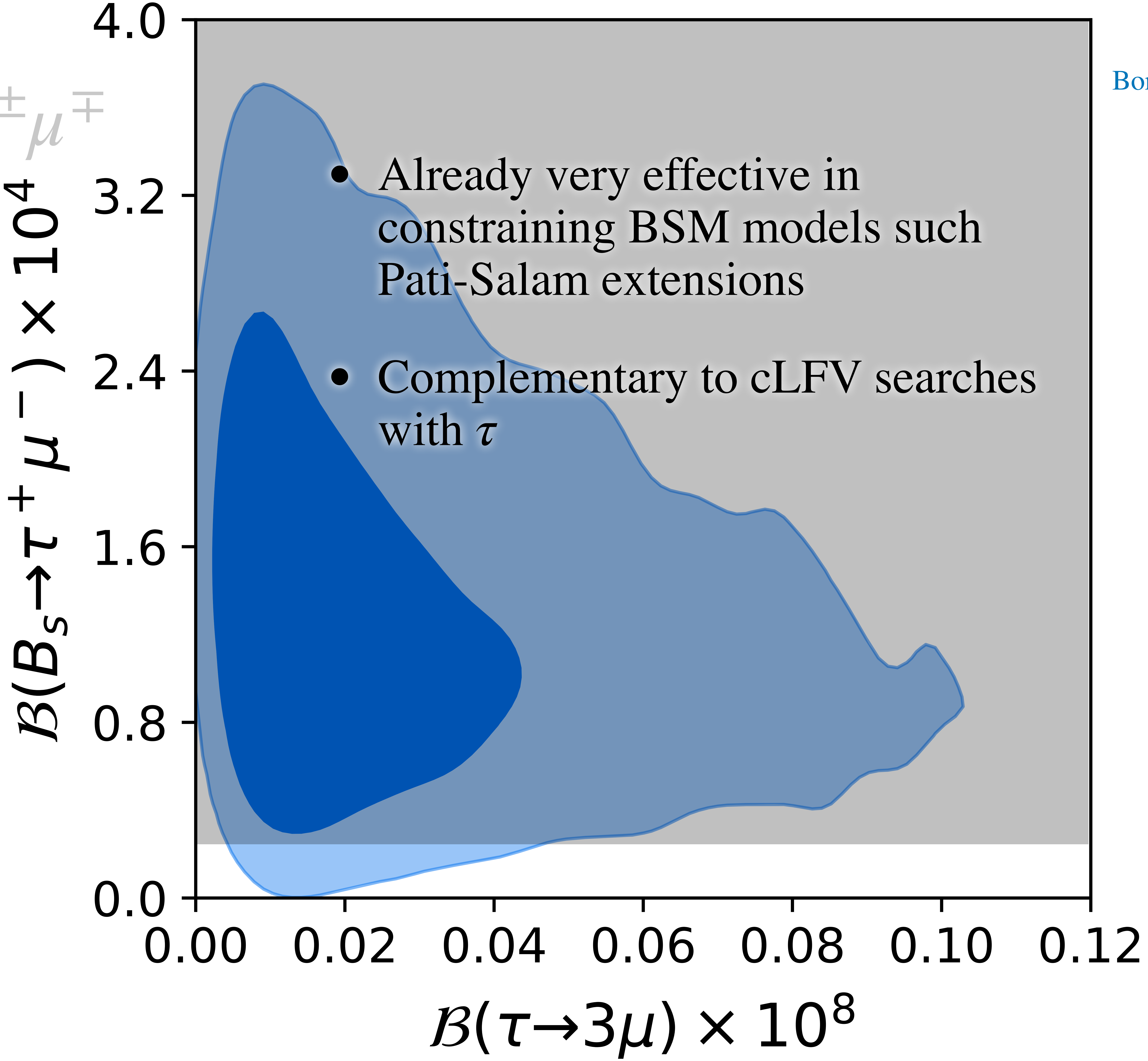
Mode	Limit	90% CL	95% CL
$B^0_s \to \tau^\pm\mu^\mp$	Observed	3.4×10^{-5}	4.2×10^{-5}
	Expected	3.9×10^{-5}	4.7×10^{-5}
$B^0 \to \tau^\pm\mu^\mp$	Observed	1.2×10^{-5}	1.4×10^{-5}
	Expected	1.6×10^{-5}	1.9×10^{-5}





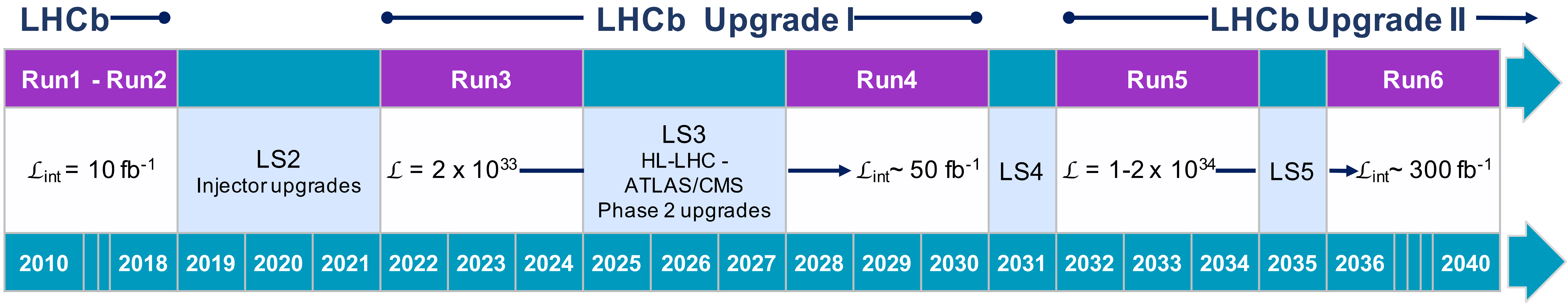
$B^0_{(s)} \to \tau^{\pm}\mu^{\mp}$

Bordone et al. JHEP10(2018)148 (2018)



$B \to \ell\ell'$ prospects

CERN-LHCC-2018-027



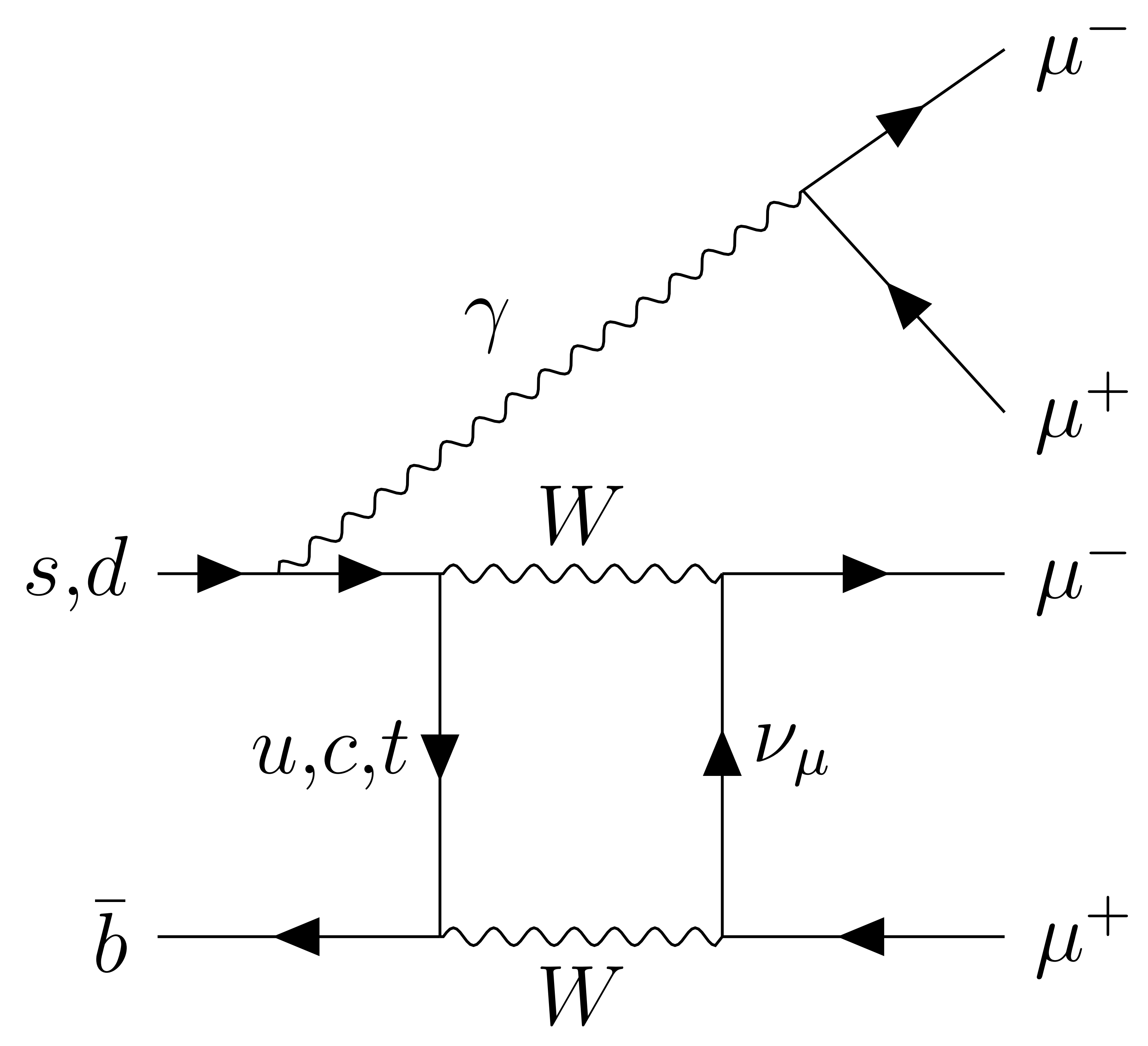
	LHCb Run1	Upgrade I	Upgrade II
$\mathscr{B}(B^0 \to e^\pm\mu^\mp)$	$< 1.3 \times 10^{-9}$	$< 2 \times 10^{-10}$	$< 9 \times 10^{-11}$
$\mathscr{B}(B_s^0 \to e^\pm\mu^\mp)$	$< 6.3 \times 10^{-9}$	$< 8 \times 10^{-10}$	$< 3 \times 10^{-10}$
$\mathscr{B}(B^0 \to \tau^\pm\mu^\mp)$	$< 1.4 \times 10^{-5}$	–	$< 3 \times 10^{-6}$

projections @95% CL

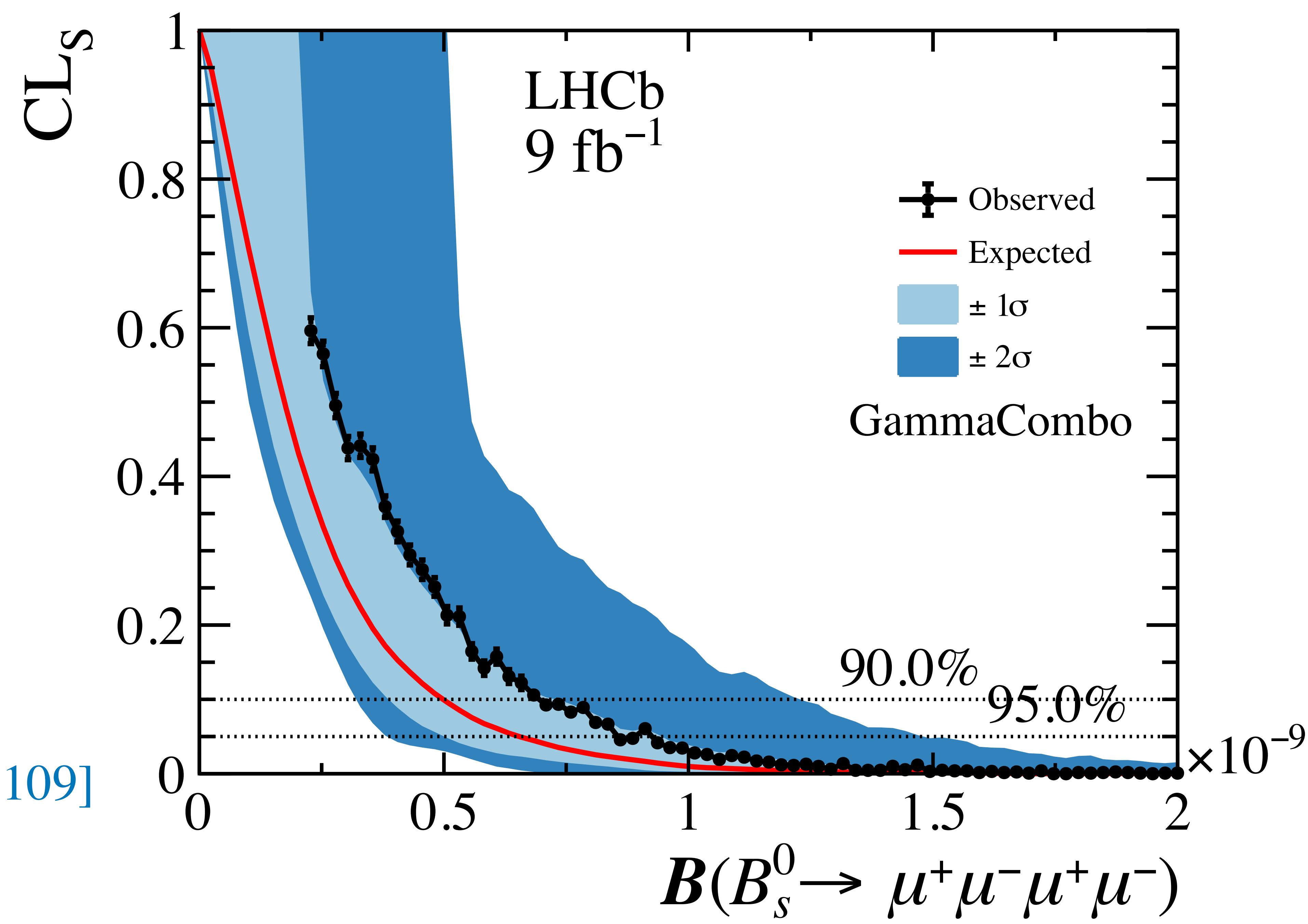
$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

- $\mathscr{B}(B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-) \sim 10^{-12(-10)}$ highly suppressed in SM
- Many SM extensions with significant enhancements of the BF, e.g. MSSM [Phys. Rev. D 85], axions [PRL 119 (2017) 031802] [JHEP 03 (2019) 008] [EPJC 79 (2019) 5]
- Using full Run 1-2 data set ($9\ \mathrm{fb}^{-1}$), search for non-resonant $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$, scalar-mediated $B^0_{(s)} \to aa$ ($m_a = 1$ GeV) and $B^0_{(s)} \to J/\psi(\to \mu^+\mu^-)\mu^+\mu^-$
- No evidence, limits at 95% CL are:

$$\mathscr{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 8.6 \times 10^{-10}$$
$$\mathscr{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 1.8 \times 10^{-10}$$
$$\mathscr{B}(B^0_s \to a(\mu^+\mu^-)a(\mu^+\mu^-)) < 5.8 \times 10^{-10}$$
$$\mathscr{B}(B^0 \to a(\mu^+\mu^-)a(\mu^+\mu^-)) < 2.3 \times 10^{-10}$$
$$\mathscr{B}(B^0_s \to J/\psi(\mu^+\mu^-)\mu^+\mu^-) < 2.6 \times 10^{-9}$$
$$\mathscr{B}(B^0 \to J/\psi(\mu^+\mu^-)\mu^+\mu^-) < 1.0 \times 10^{-9}$$



[JHEP 03 (2022) 109]



$D^0 \to \mu^+\mu^-$

- Opportunity to study FCNC in the upper sector, effectively GIM suppressed and helicity suppressed.

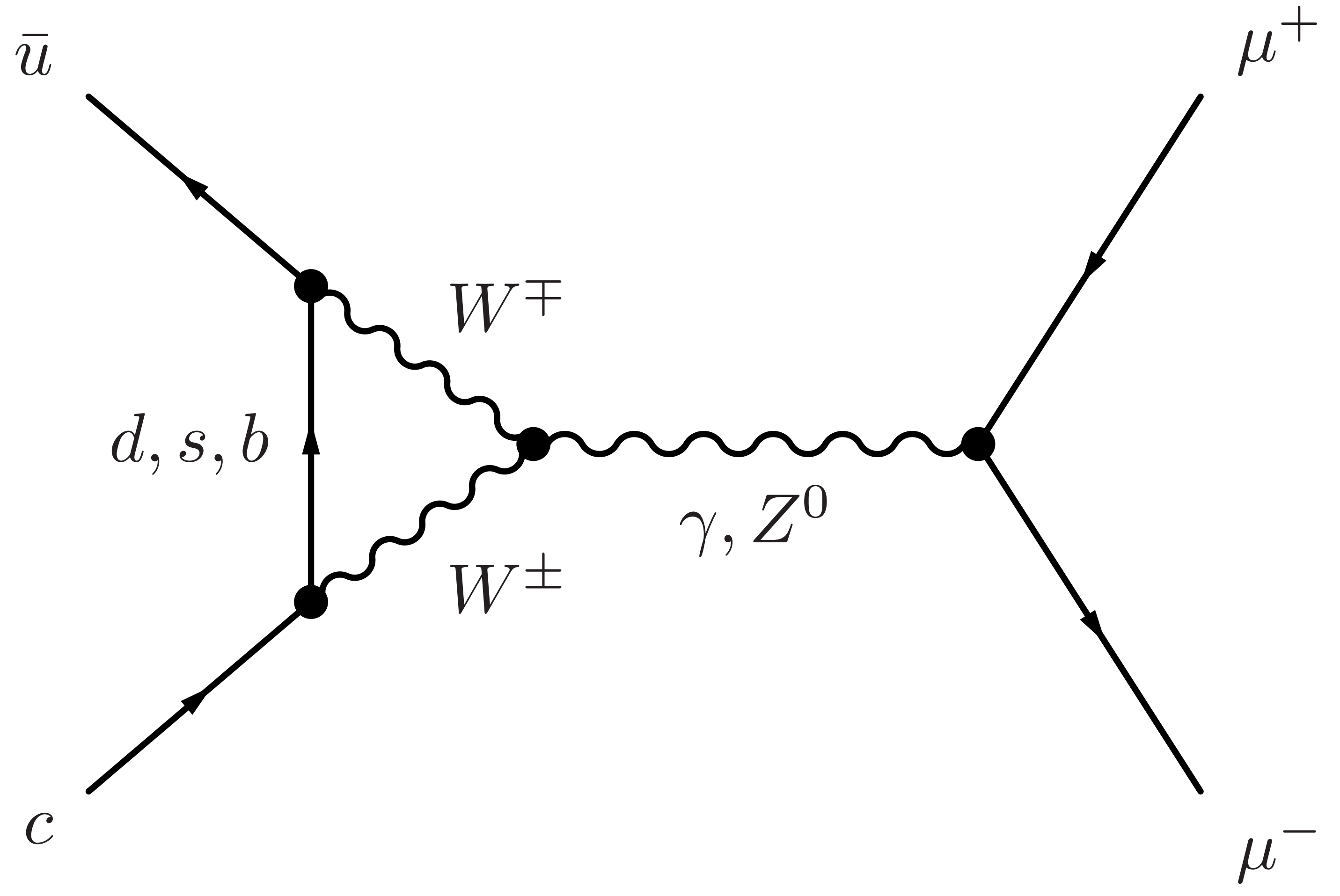
- Two contributions:

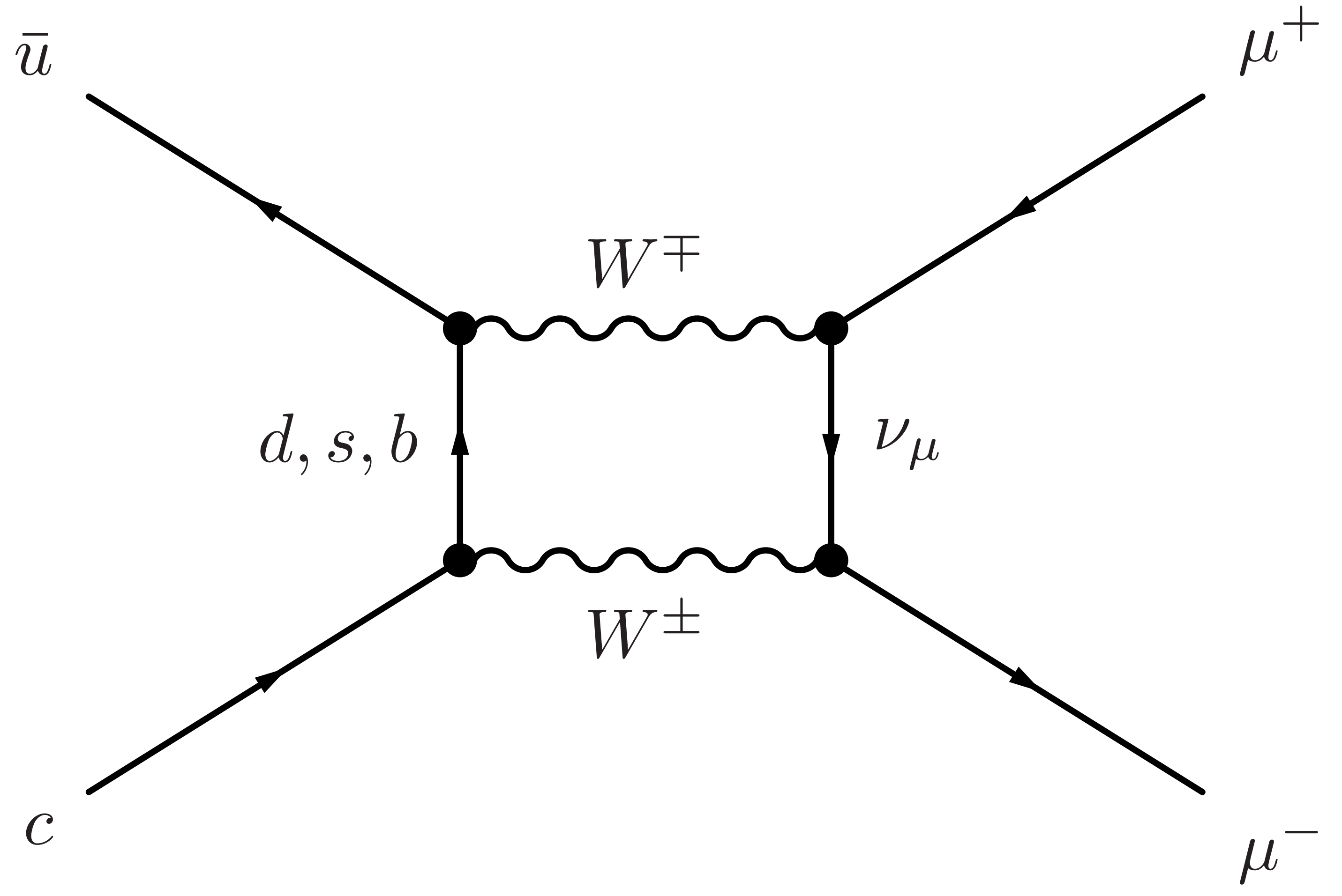
  - Short distance extremely suppressed $\sim 10^{-18}$ [PRD 66 (2002) 014009]

  - Long distance with two-photons intermediate state [PRD 66 (2002) 014009]. Upper limit from $D^0 \to \gamma\gamma$ search $\mathcal{B}^{(\gamma\gamma)}(D^0 \to \mu^+\mu^-) < 2.3 \times 10^{-11}$ @ 90 % CL

- Useful to constrain model of NP with extra particles (e.g. vector-like fermions [JHEP 10 (2015) 027])

- Previous upper limit from LHCb with 2011 data set (0.9 fb^{-1}) $\mathcal{B}(D^0 \to \mu^+\mu^-) < 7.6 \times 10^{-9}$ @ 95 % CL



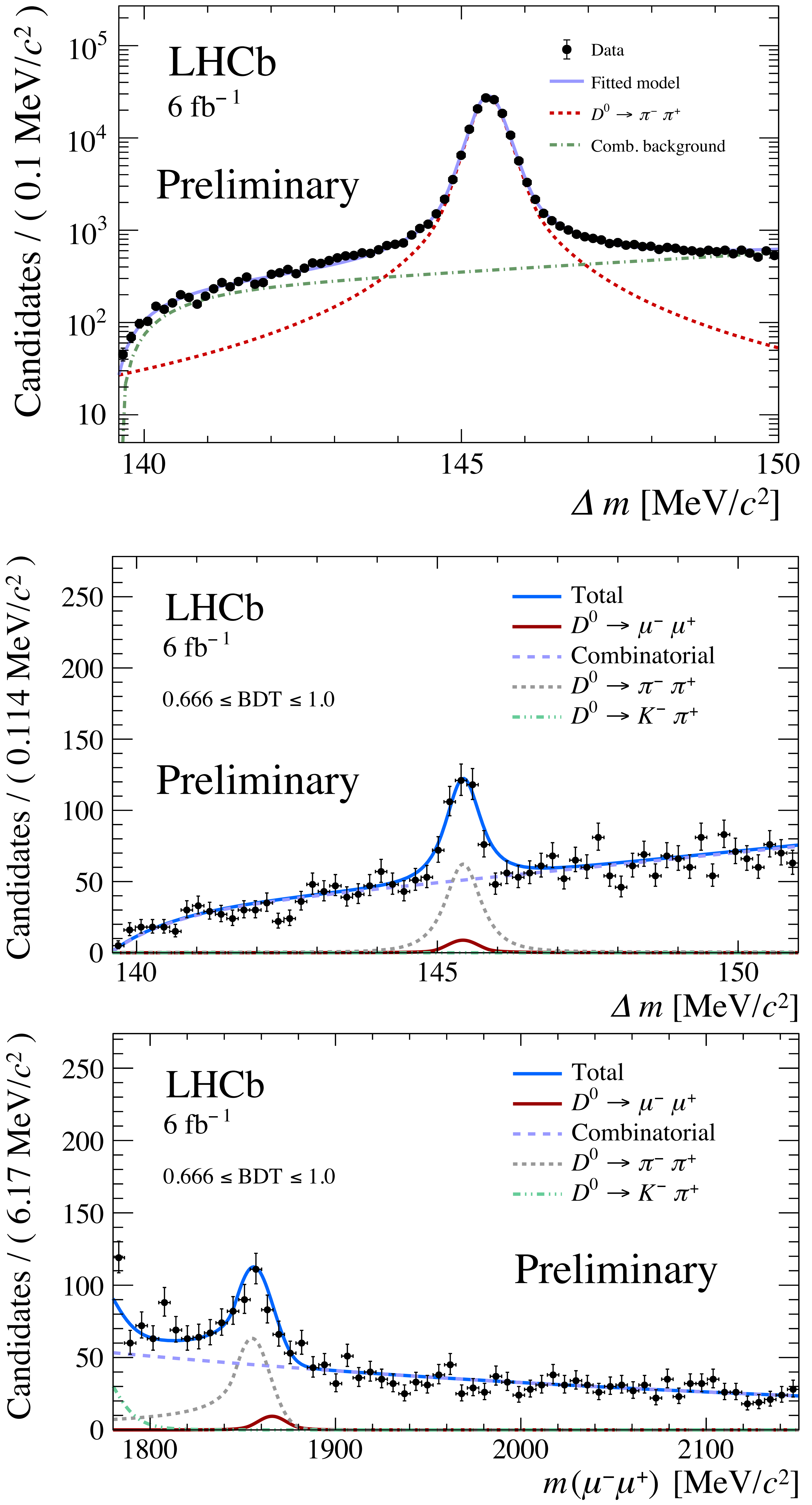


$D^0 \to \mu^+\mu^-$

preliminary

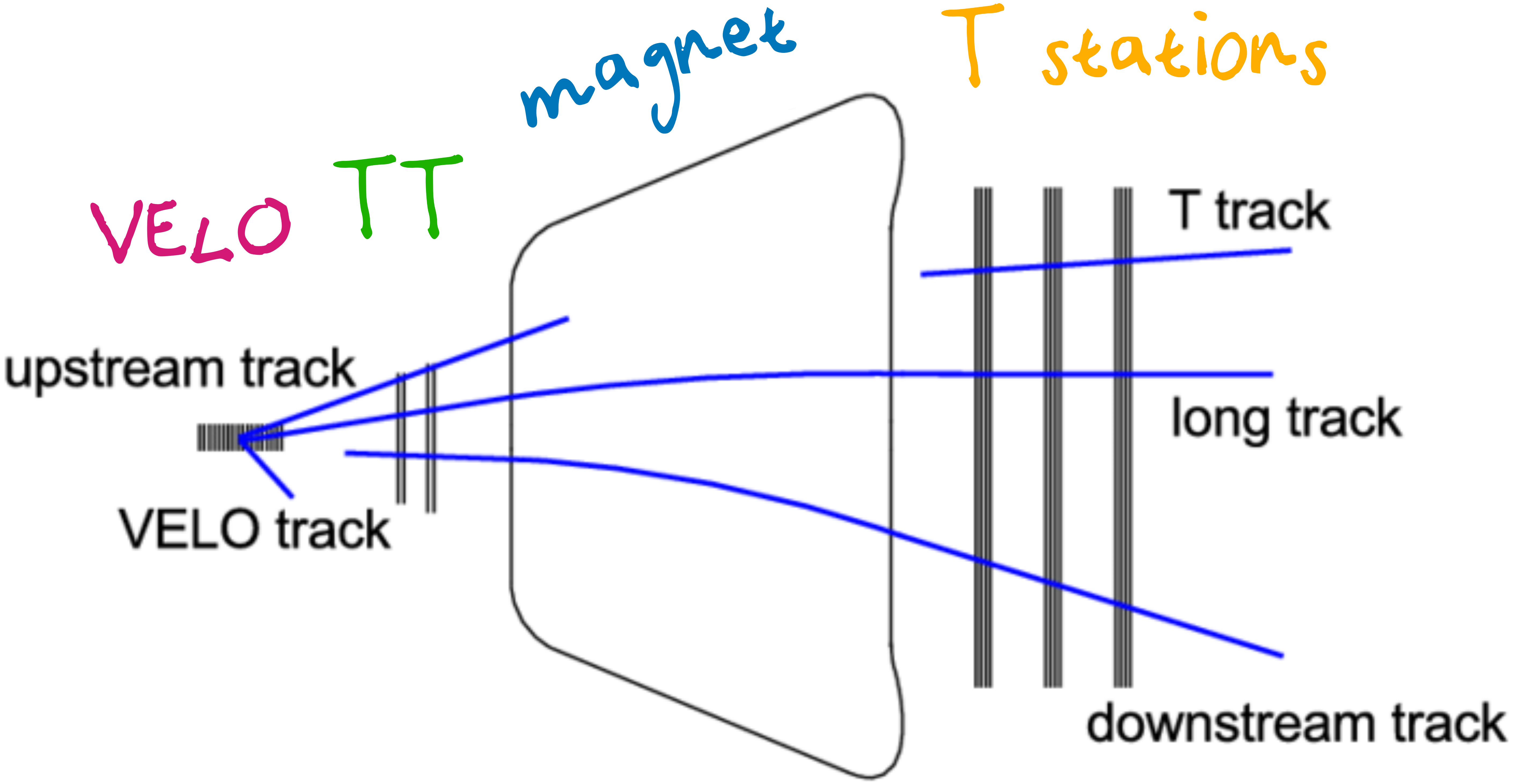
[LHCb-PAPER-2022-029]

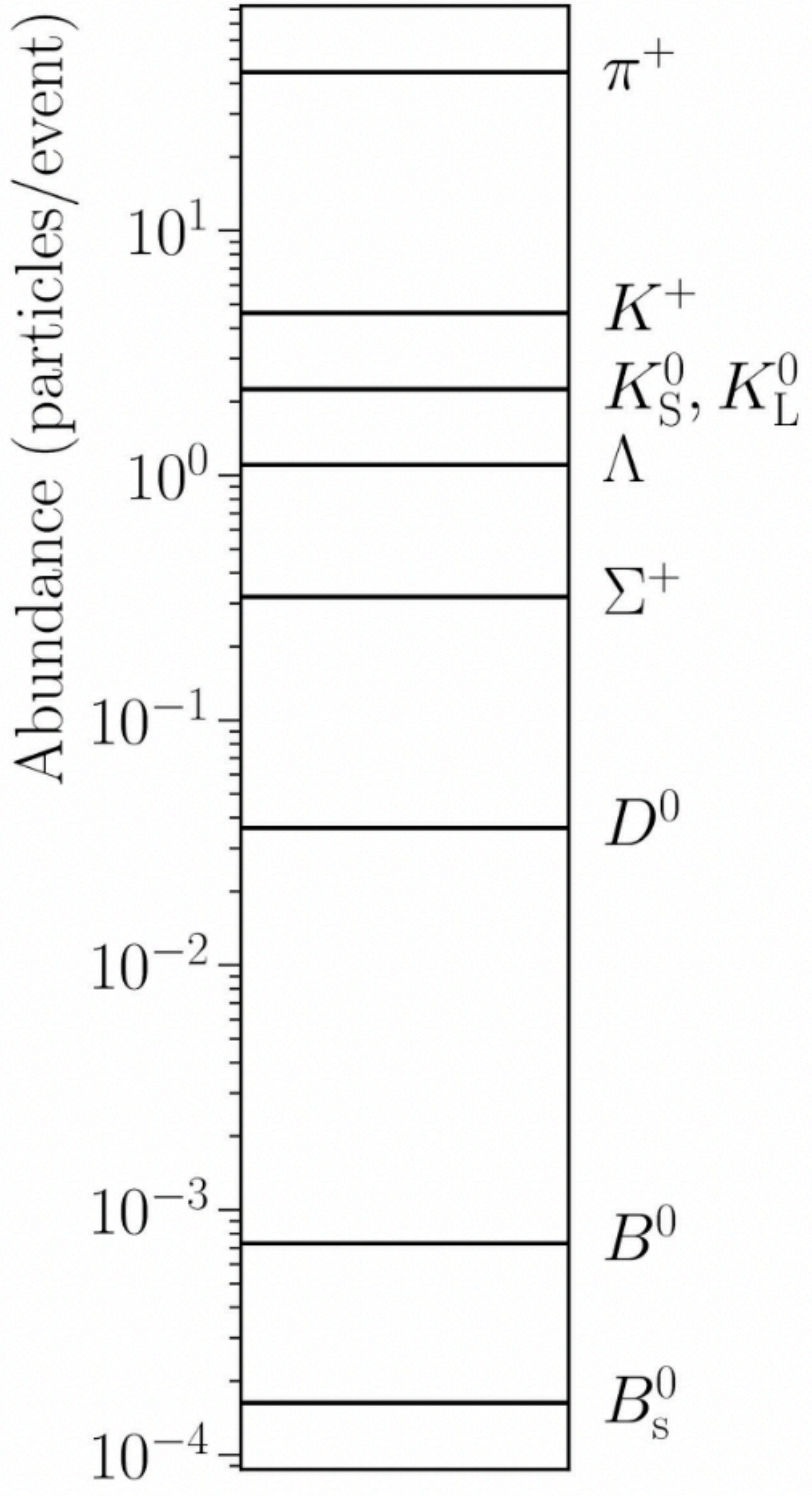
- Blind analysis on full Run1+2 ($9\,\mathrm{fb}^{-1}$)
- D^0 coming from $D^{*+} \to D^0\pi^+$ ($\mathcal{B} \sim 68\,\%$)
- Normalisation mode $D^0 \to h^-\pi^+$
- Selection strategy chosen to minimise the combinatorial + misID backgrounds: BDT + PID
- Signal yield from a 2D unbinned ML fit to $m(D^0)$ and Δm simultaneously on 3 BDT cat. and 2 Run period
- Preliminary result: $\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.9(3.3) \times 10^{-9}$ @ 90(95) % CL
  - main systematics from normalisation mode trigger
- Expected for the Upgrade:
  - Upgrade I ($50\,\mathrm{fb}^{-1}$): $\mathcal{B}(D^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10}$ @ 90 % CL
  - Upgrade II ($300\,\mathrm{fb}^{-1}$): $\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-10}$ @ 90 % CL



Strange decays at LHCb

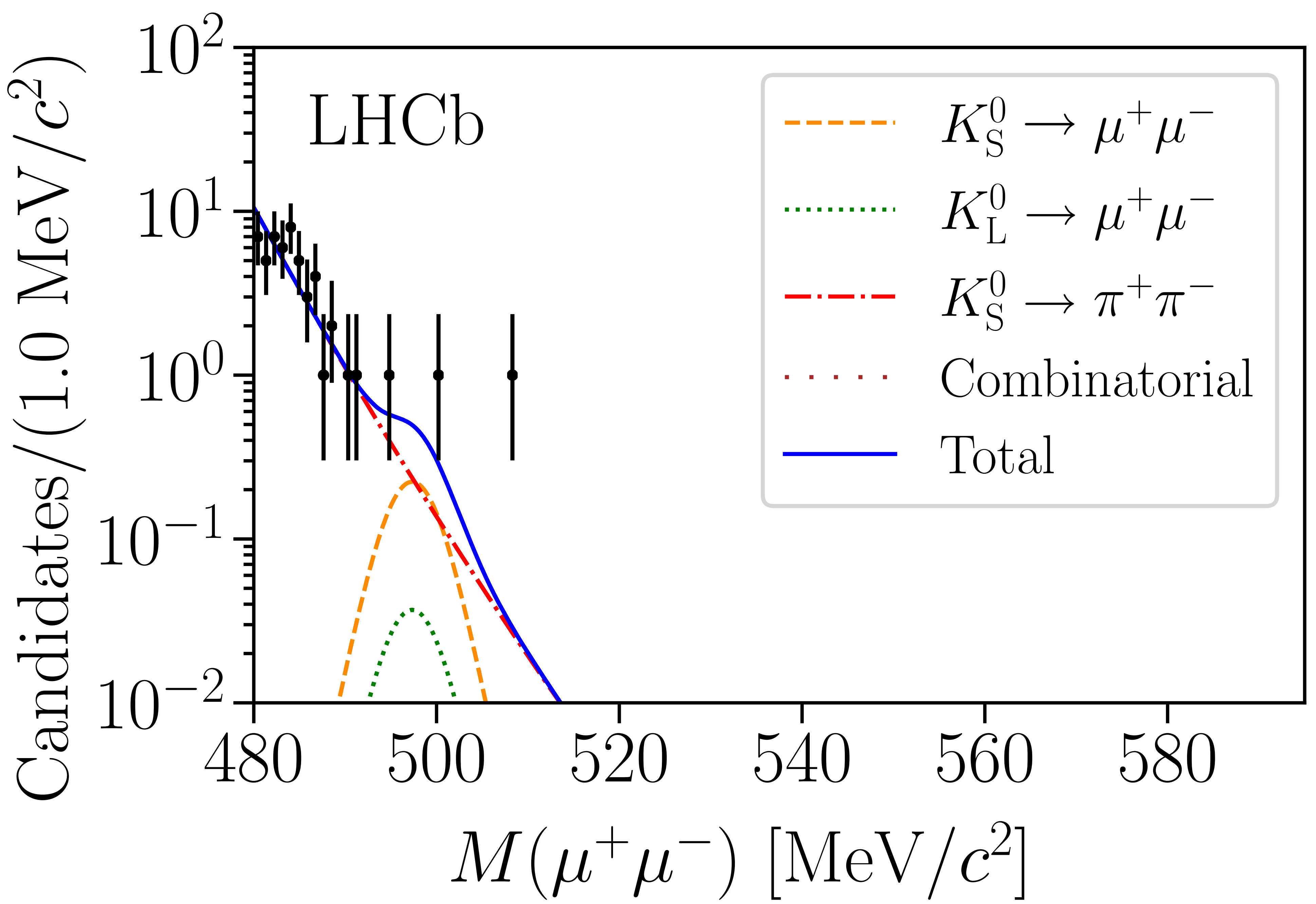
- LHC"b" optimised for b physics but large production of charm and strange quarks ($\mathcal{O}(10^{13})$ K^0_S/fb^{-1} with decay vtx in VELO acceptance)

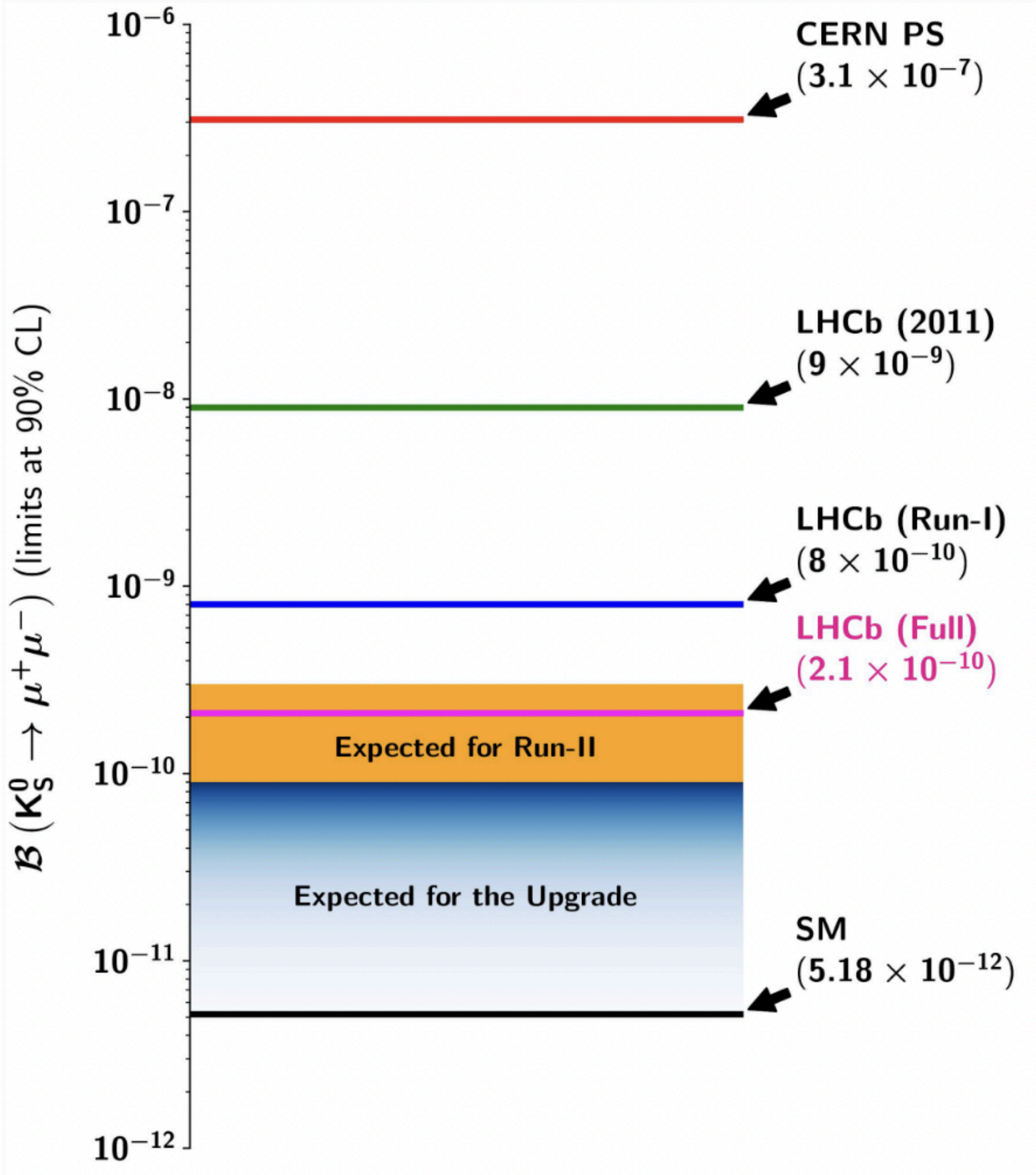




Strange decays at LHCb

- $K_S^0 \to \mu^+\mu^-$ highly suppressed in the SM
- Blind analysis on full Run2 data sample combined with Run1 [PRL 125, 231801 (2020)]

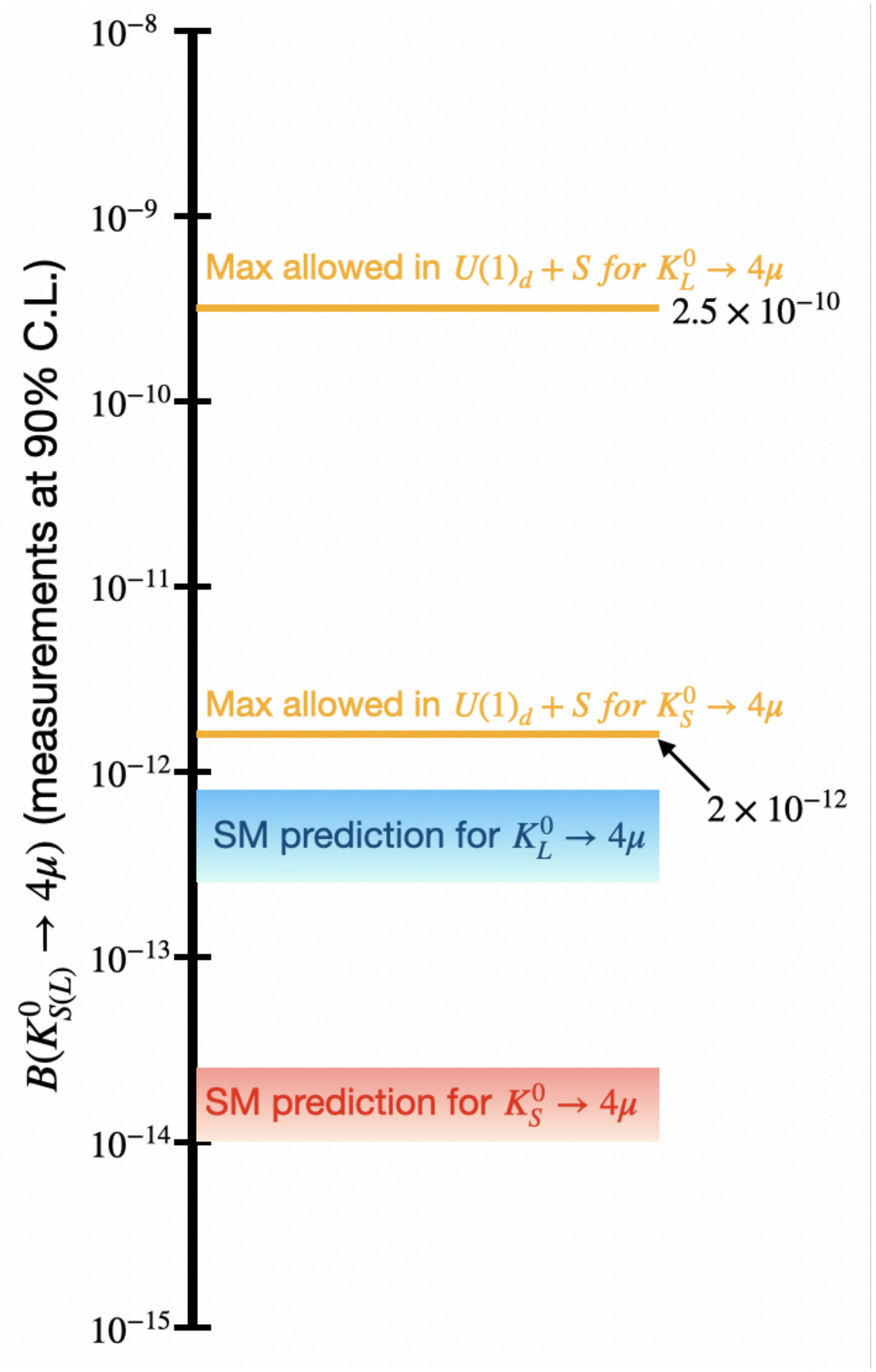




$K^0 \to \mu^+\mu^-\mu^+\mu^-$

preliminary

- Highly constrained by phase space, very low background. SM prediction [Eur. Phys. J. C 73 (2013) 2678]:
  - $\mathscr{B}(K^0_{S(L)} \to \mu^+\mu^-\mu^+\mu^-) \sim 10^{-14}(10^{-13})$
- Dark photons models like $U(1)_d + S$ can enhance the SM branching fraction prediction up to two orders of magnitude. [arXiV:2201.07805]

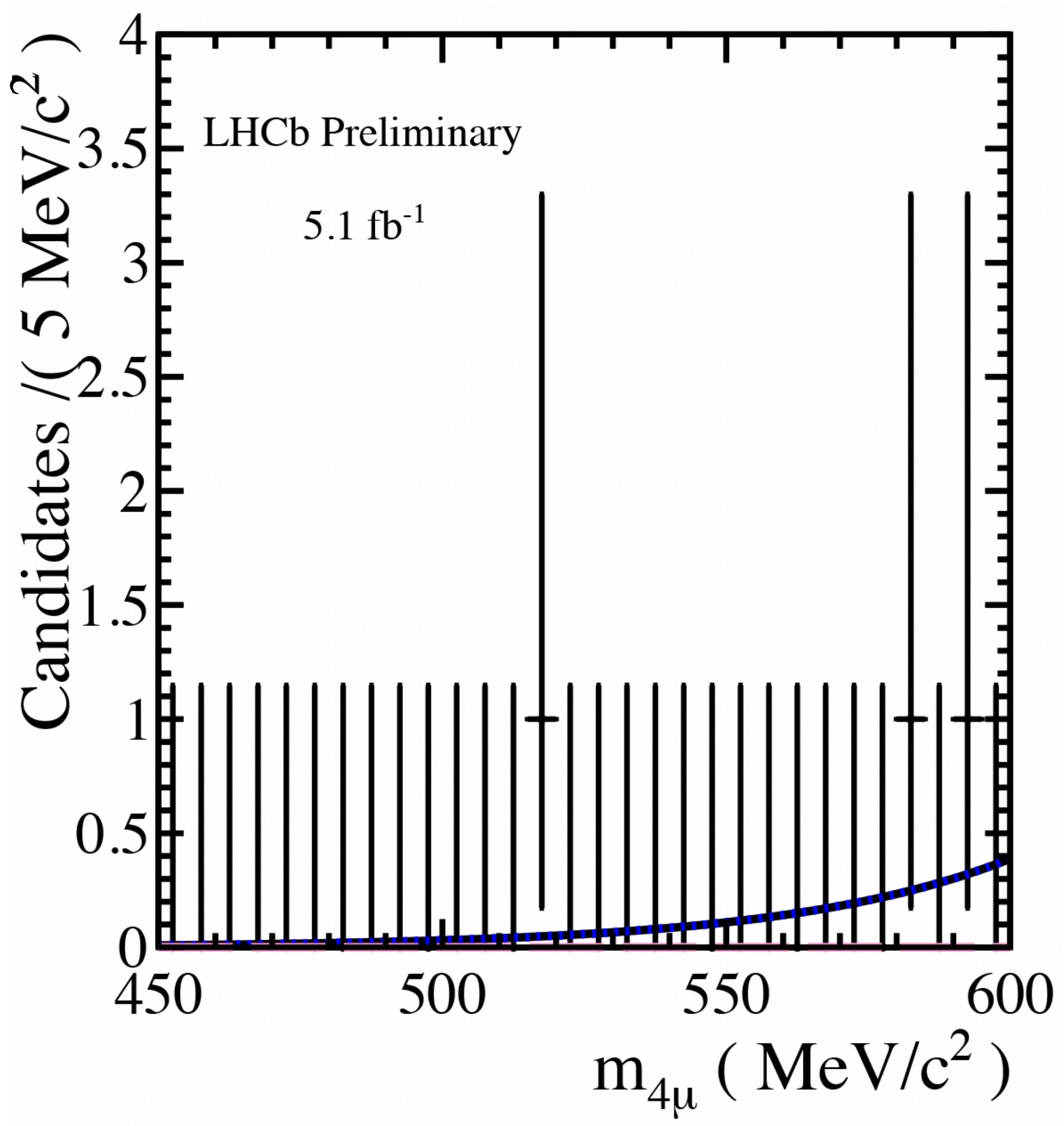


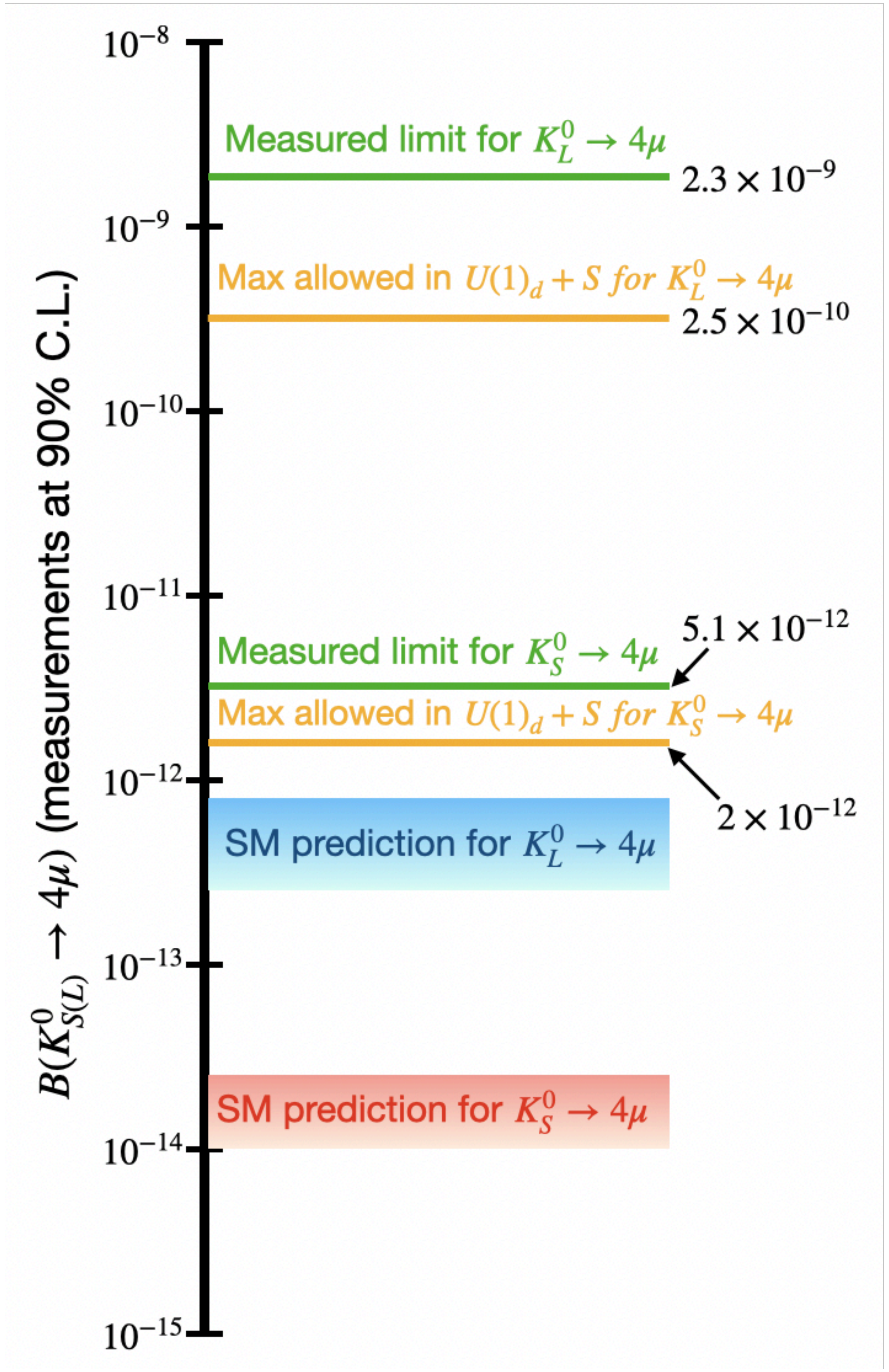
$K^0 \to \mu^+\mu^-\mu^+\mu^-$

preliminary

[LHCb-PAPER-2022-035]

- Blind analysis on 2016-2018 data (5.1 fb^{-1})
- $K_S^0 \to \pi^+\pi^-$ is used as normalisation mode
- Potential peaking background (e.g. $K^0 \to \pi + \pi^- e^+ e^-$) found negligible
- Main background source: random combination of tracks from IP or inelastic collision in the material
  - BDT used to improve signal/bkg separation
- No evidence of signal
- Improvement of an order of magnitude is expected in the sensitivity thanks to the hardware-less trigger.

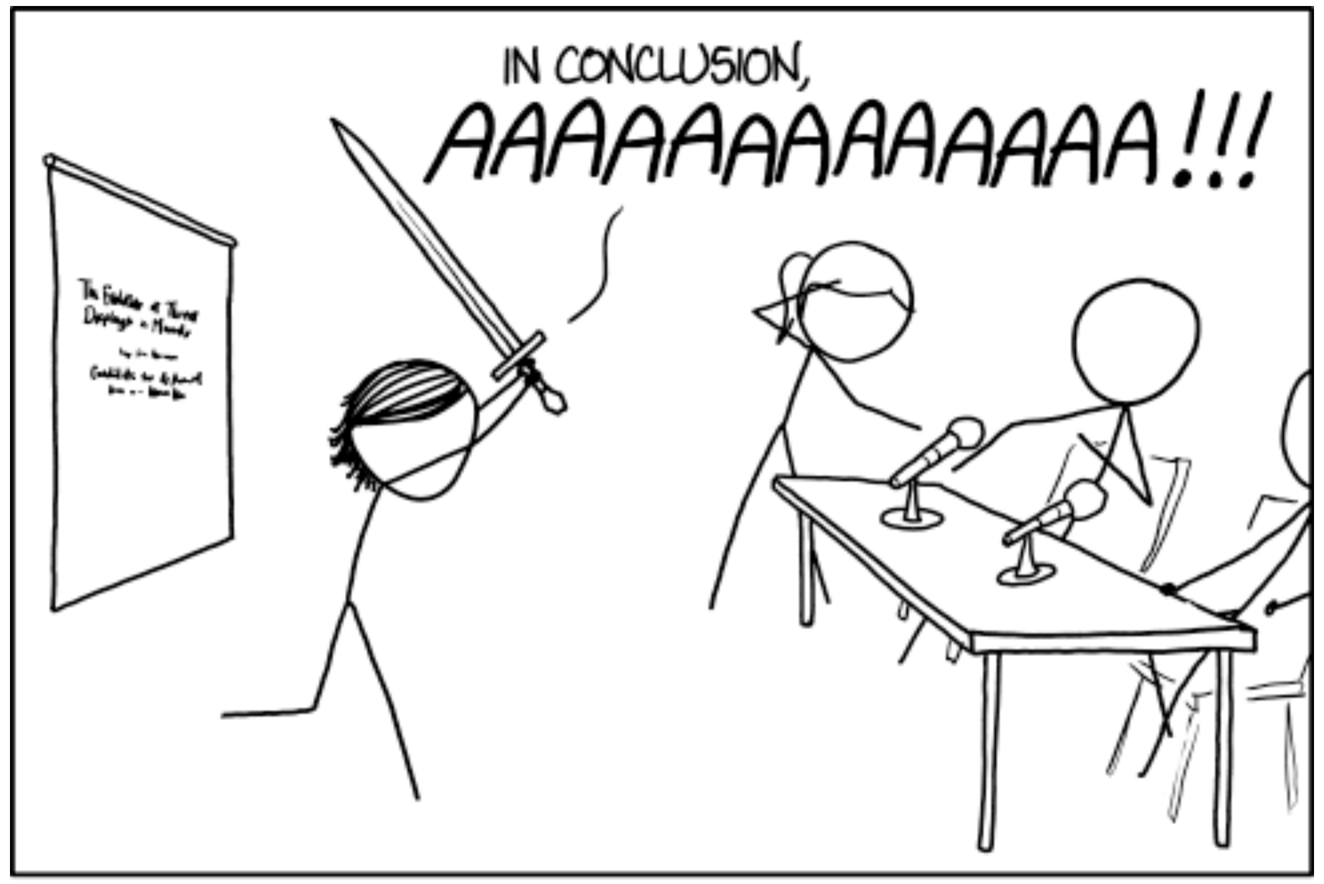




Conclusions

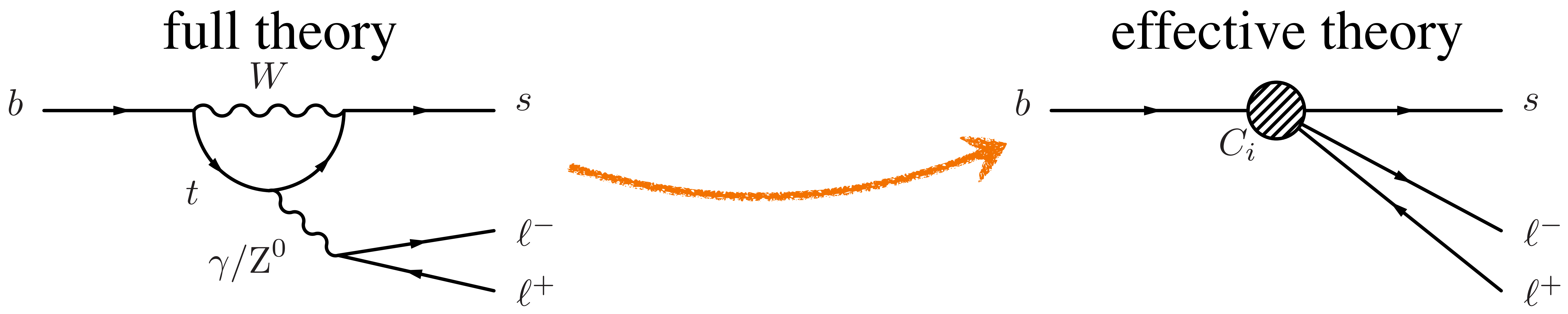
- Purely-leptonic decays are sensitive probes for New Physics effects
- SM describes large majority of results with excellent precision
  - Complementary information to B anomalies in semileptonic decays
- Run 3 starting now allowing an unprecedented sensitivity for NP effects
  - Full software trigger, including higher efficiencies for leptons, especially electrons!
  - Good prospects for fully leptonic decays!
- Moreover, several updates with full Run 1 and 2 data sample in preparation

BACKUP!



THE BEST THESIS DEFENSE IS A GOOD THESIS OFFENSE.

(No) introduction!

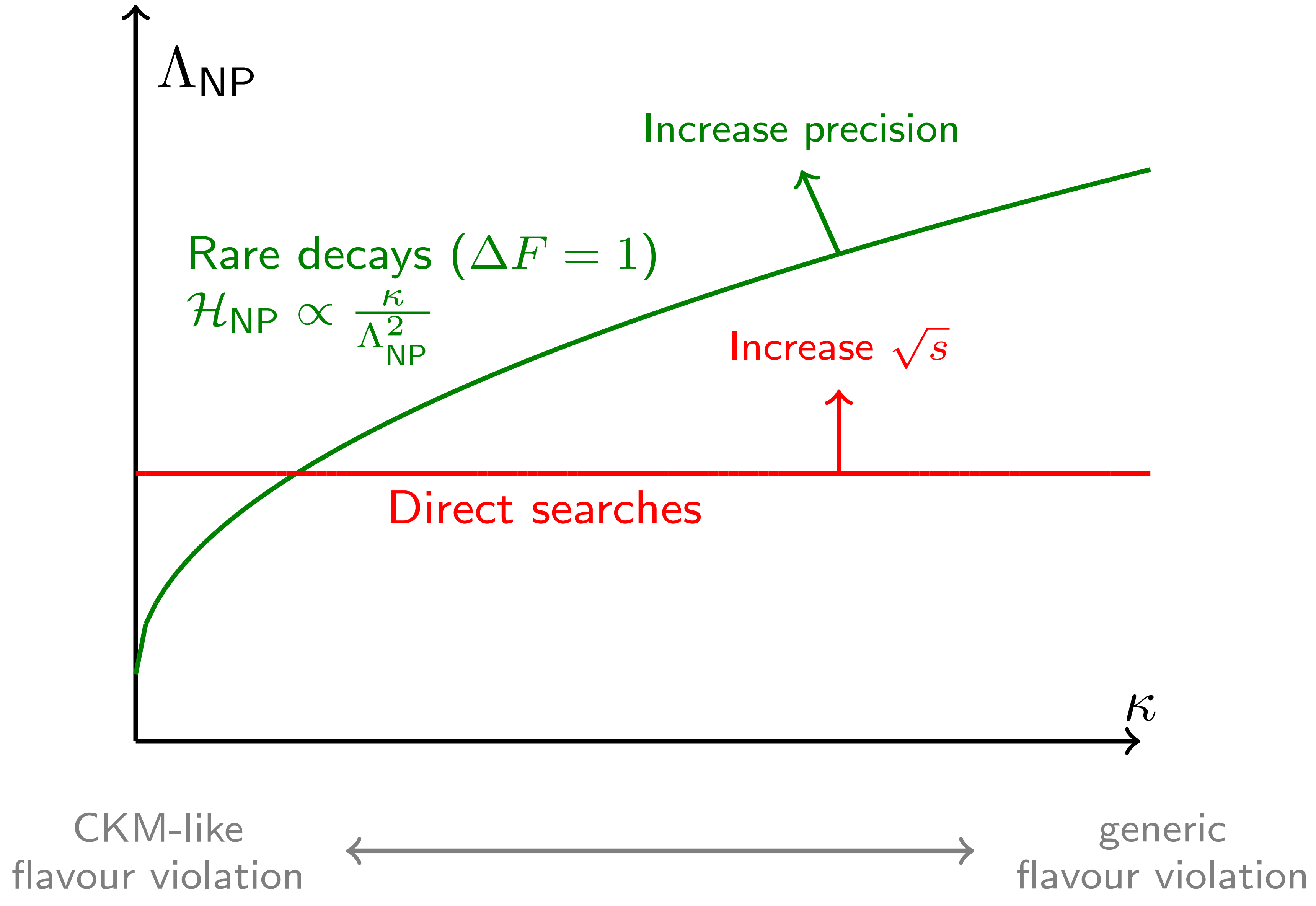


- Model independent description in effective field theory

$$\mathscr{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) \mathscr{O}_i \qquad \Delta\mathscr{H}_{\text{NP}} = \frac{\kappa}{\Lambda_{\text{NP}}^2} \mathscr{O}_{\text{NP}}$$

- Direct searches limited by beam energy

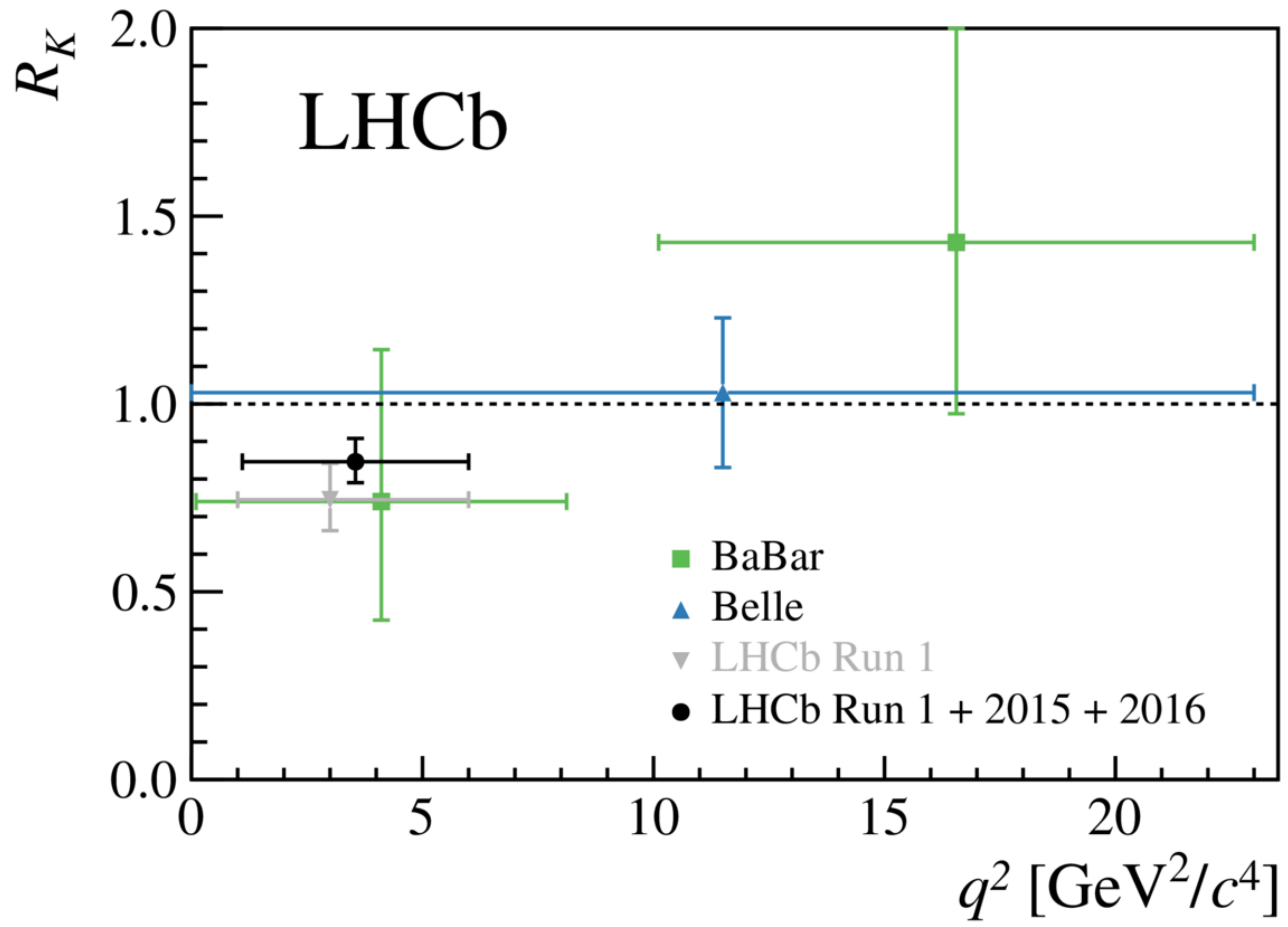
- Rare decays depends on coupling κ and measurement precision

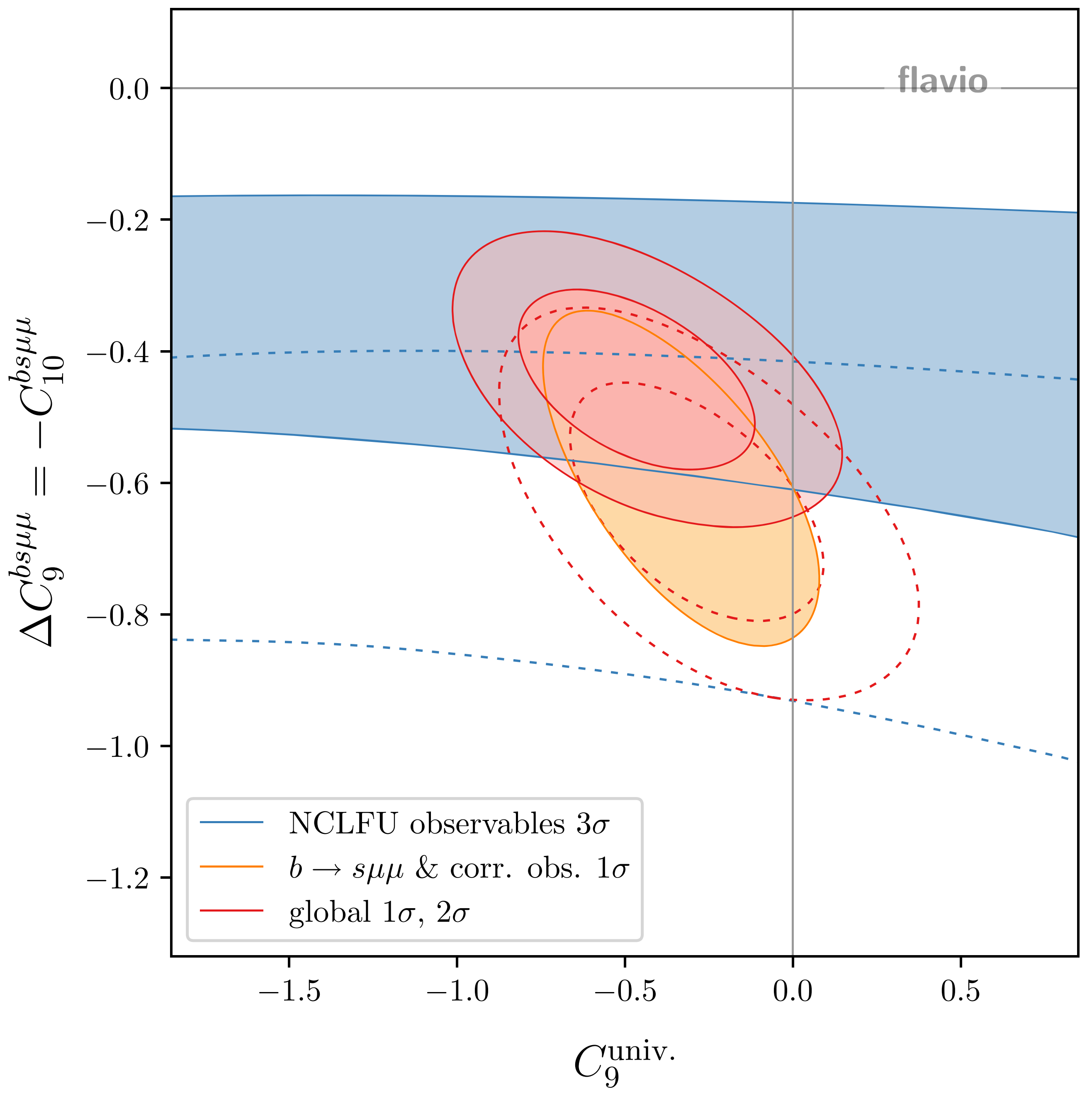


LFU and consequences

- Lepton Flavour Universality (LFU): couplings with gauge bosons of all leptons are equal
- QCD uncertainties completely cancel in the ratio
- Cleaner observables can be used to probe NP effects
- Hints of deviation from LFU test consistent with $b \to s\mu\mu$ BF and angular analyses if NP only in μ
- Possible Lepton Flavour Violation (LFV) as possible consequence

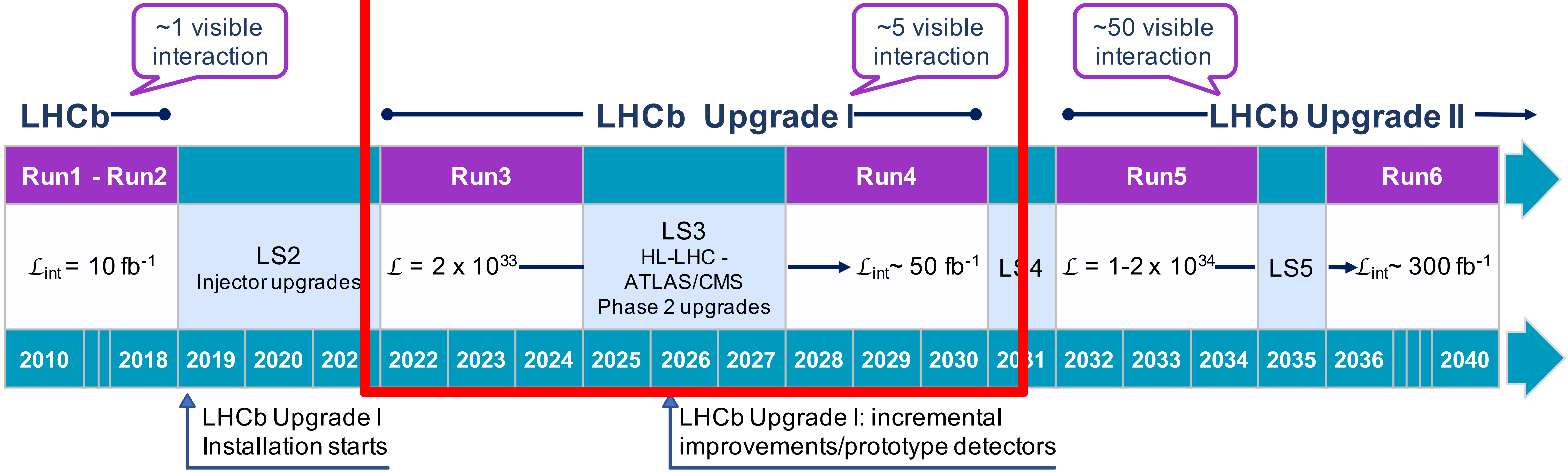
Phys. Rev. Lett. 122 (2019) 191801





Aebischer et al, Eur. Phys. J. C (2020) 80:252

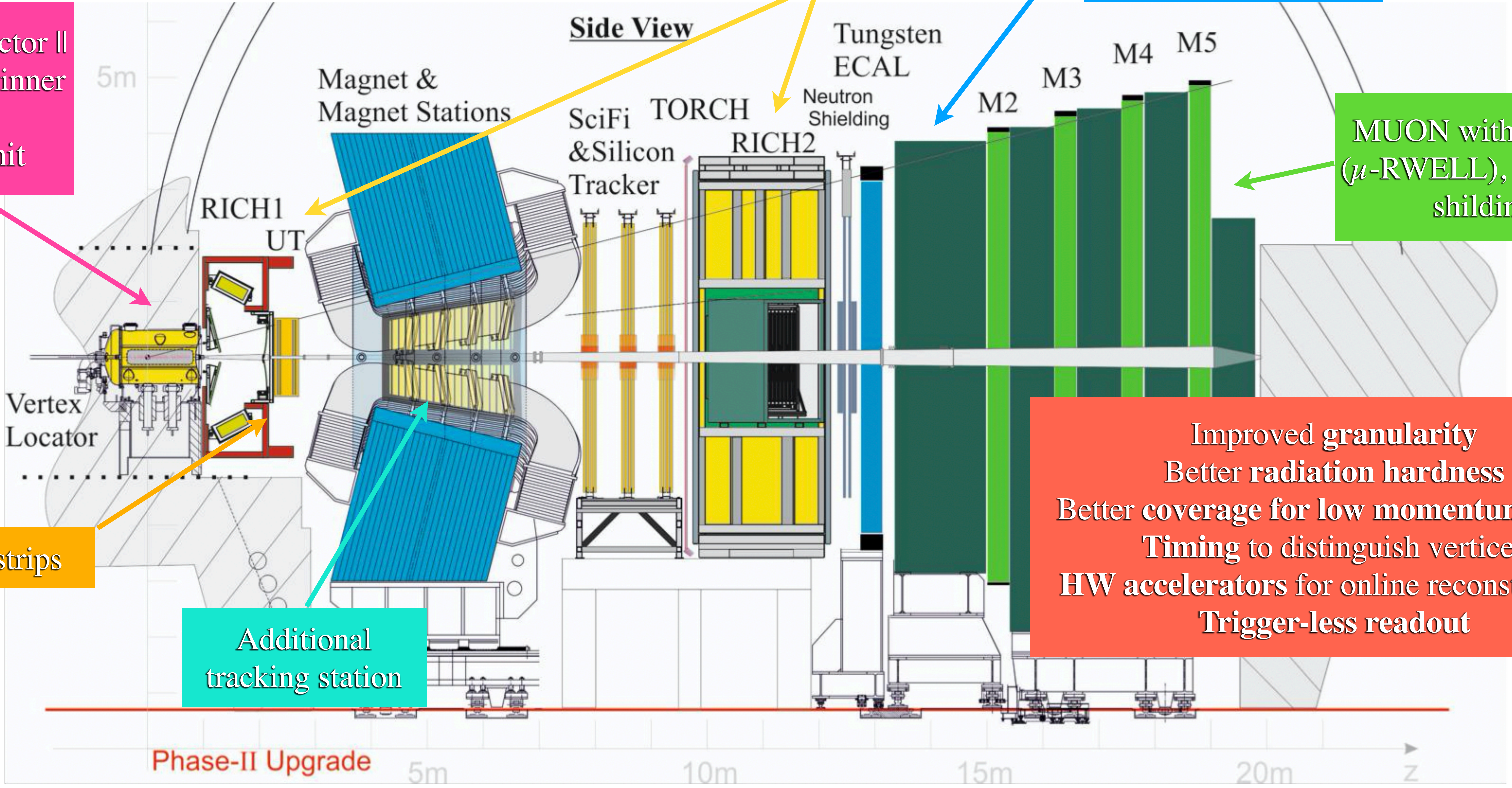
Upgrade and plans



- Preparing the upgrade for Run3 and Run4 during LS2
  - Full software trigger and new readout system, all detector at 40MHz (32 Tbps throughput)
  - Replace tracking detectors + PID + VELO, $\mathscr{L} = 2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Consolidate PID, tracking and ECAL during LS3
- Phase-II upgrade during LS4:
  - New detector technologies, $\mathscr{L} = 1.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Detector upgrade I

Detector upgrade II



RICH with new photon detectos $\sigma_t < 100$ ps/photon, TORCH detector

ECAL with finer segmentation and timing with $\sigma_t \sim 20 - 50$ ps

New Vertex Detector II smaller pixels, thinner sensors, $\sigma_t < 200$ ps/hit

MUON with MPGD (μ-RWELL), modified shilding

Si-strips

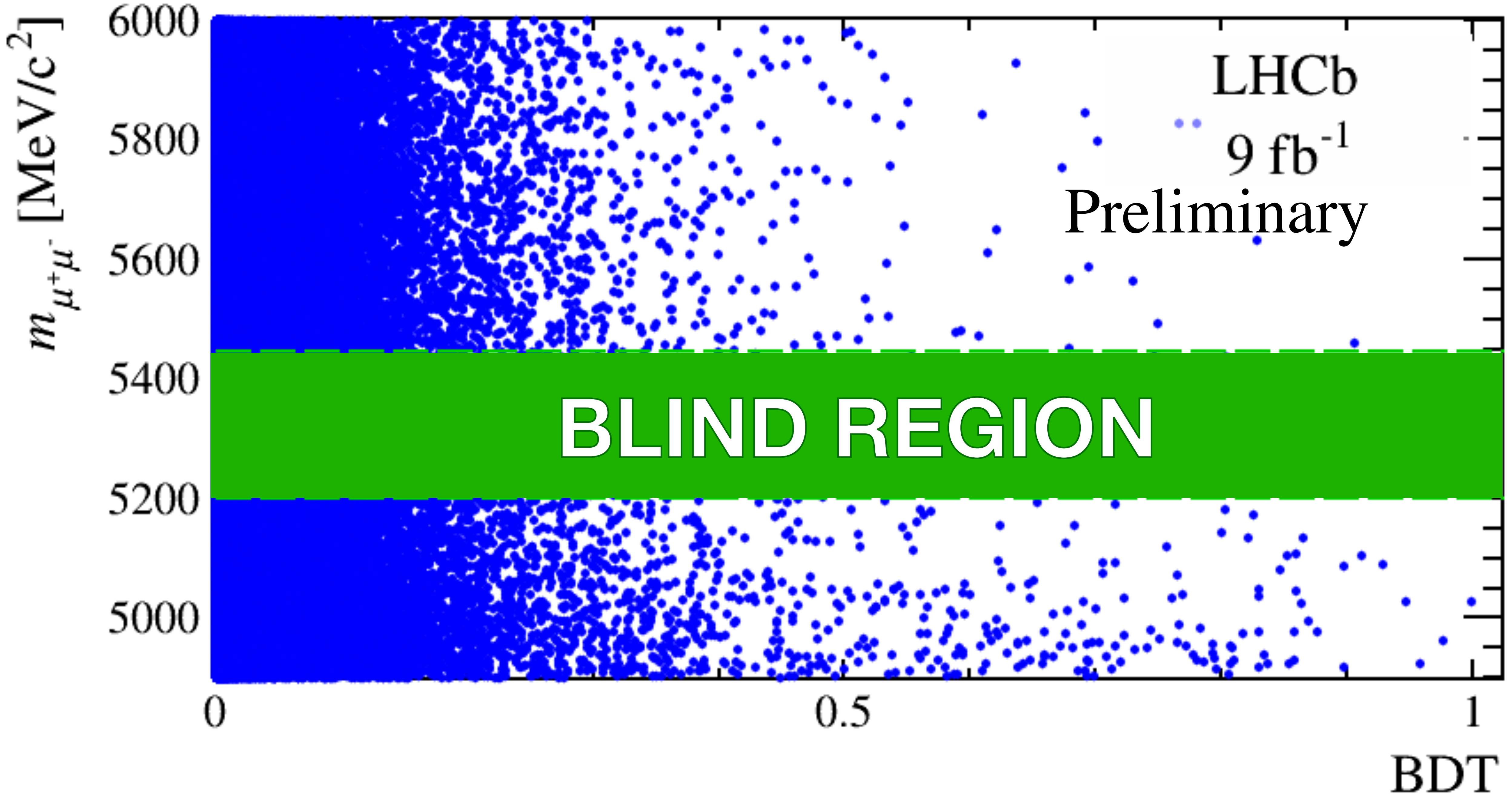
Additional tracking station

Improved **granularity**
Better **radiation hardness**
Better **coverage for low momentum** tracks
Timing to distinguish vertices
HW accelerators for online reconstruction
Trigger-less readout

Analysis strategy

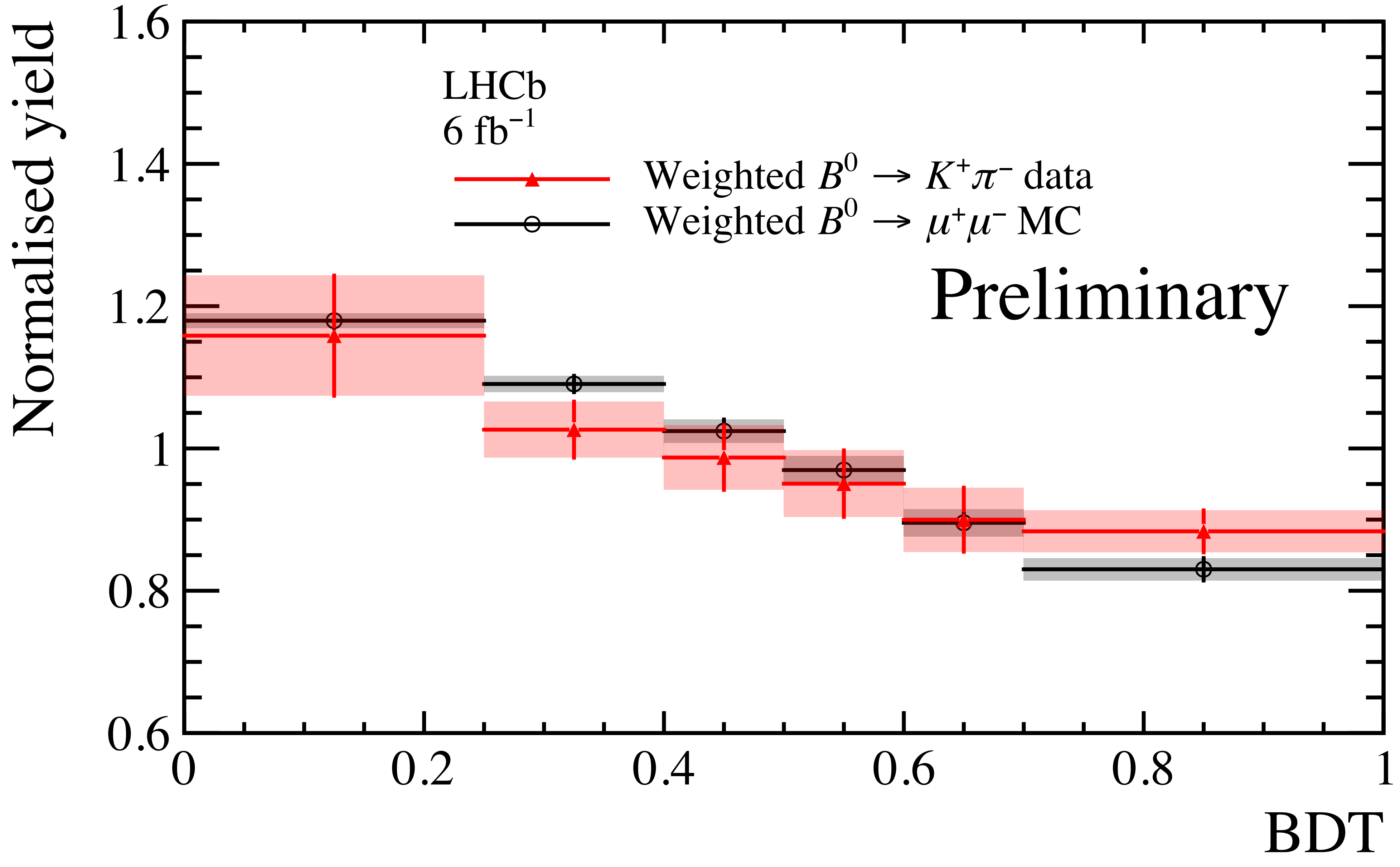
LHCB-PAPER-2021-007

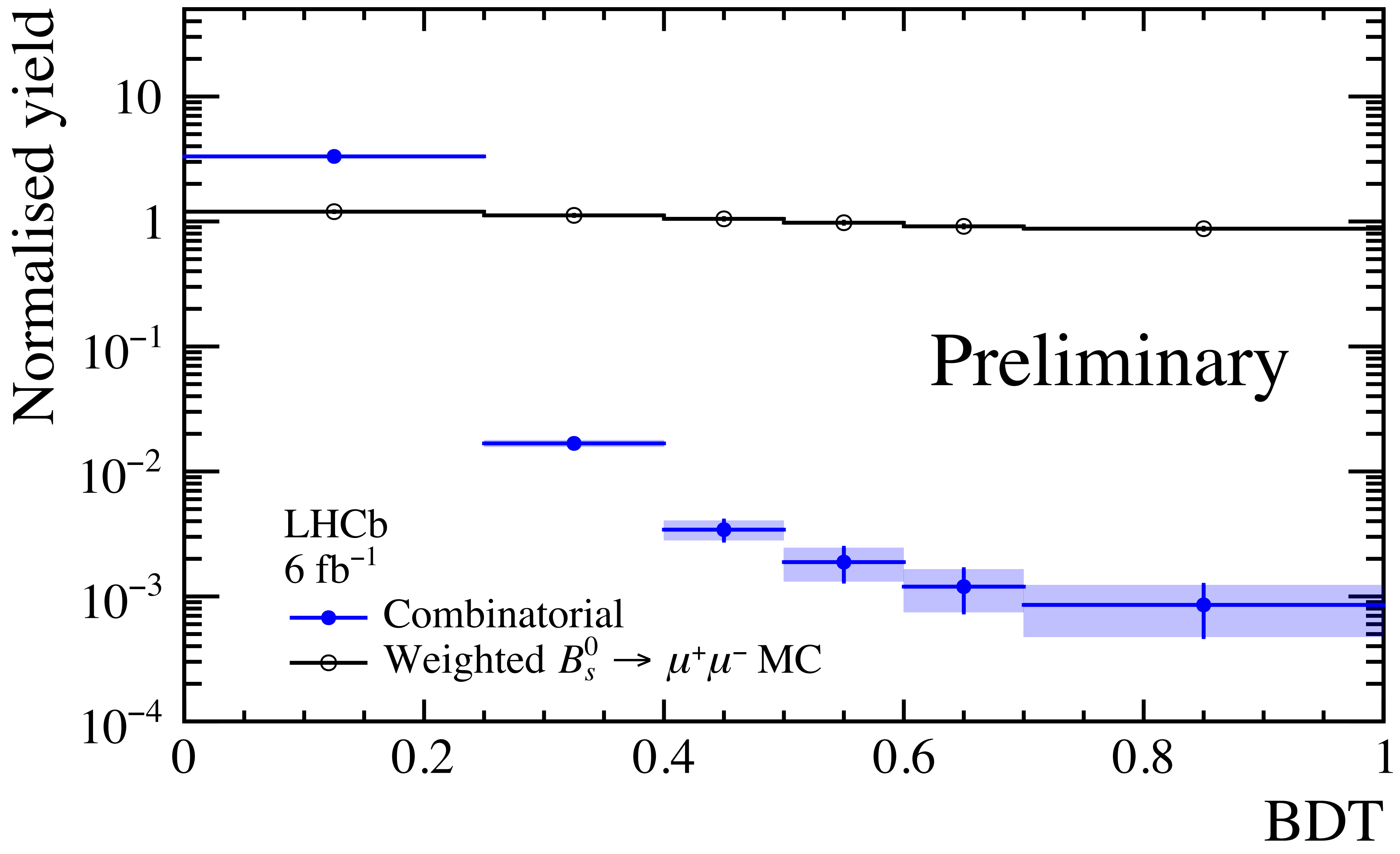
- $3fb^{-1}$ of Run1 at 7 and 8 TeV and $6fb^{-1}$ of Run2 at 13 TeV LHCb dataset used (almost doubling the previous dataset)
- Search in $m_{\mu\mu} \in [4.9, 6.0]\mathrm{GeV}/c^2$
    - opportunity to search for untagged ISR $B \to \mu\mu\gamma$ decays
- Main background due to combinatorics of two μ's.
- Signal/Background separation obtained through $m_{\mu\mu}$ and BDT trained on two body kinematics and topology



BDT calibration

- New BDT calibration procedure using simulated events:
  - kinematics + occupancy + PID + trigger corrected using data control channels
  - New procedure compared with previous calibration using $B \to hh'$ decays with larger uncertainties
  - Combinatorial background peaking at low BDT region





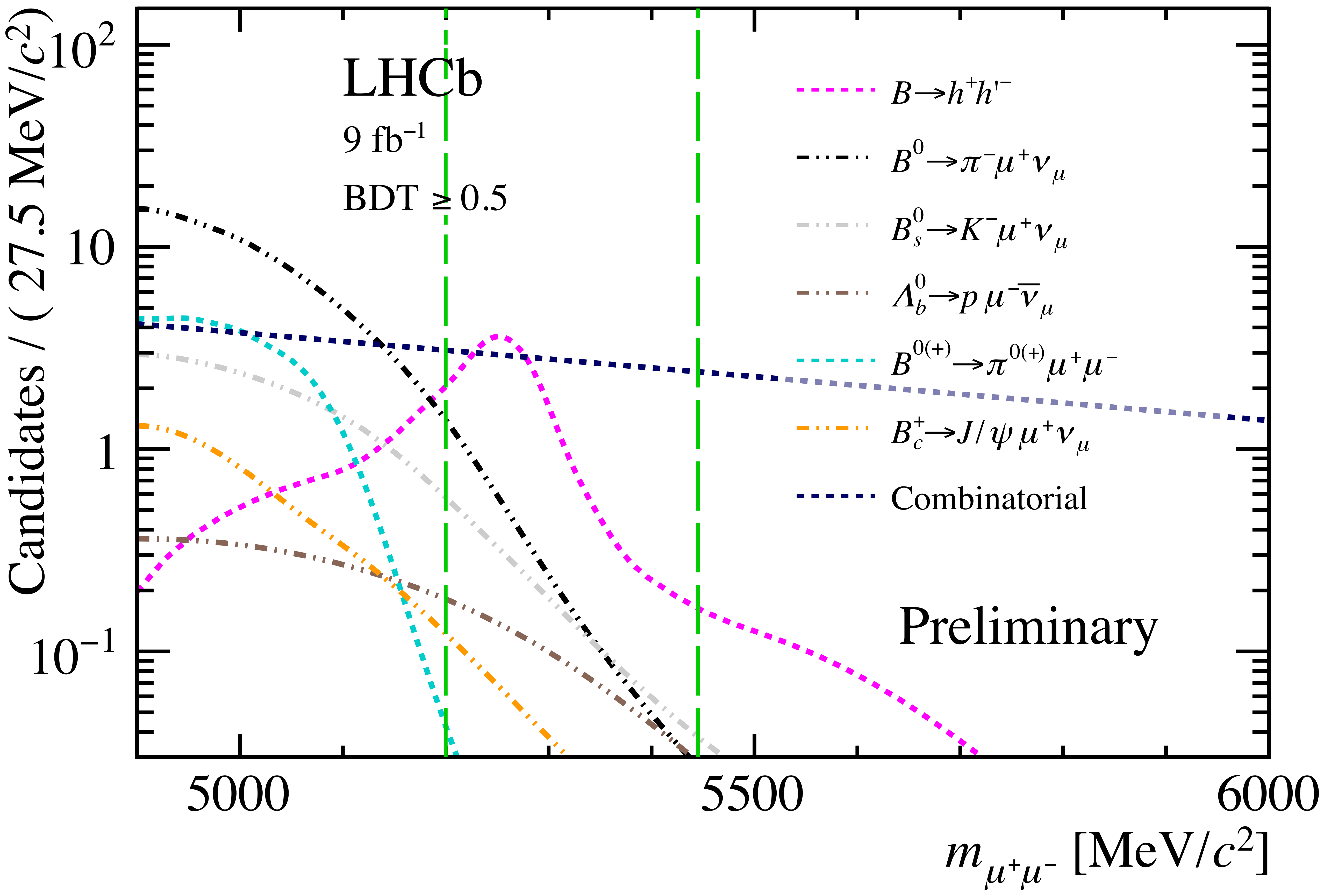
Background sources

LHCB-PAPER-2021-007

- In addition to the main combinatorial background (exponential shape), other two categories populate the lower mass range:
  - MisID: $B \to hh'$, $X_b \to h\mu\nu$
  - Part-Reco: $B \to \pi\mu^+\mu^-$, $B_c^+ \to J/\psi\mu^+\nu$

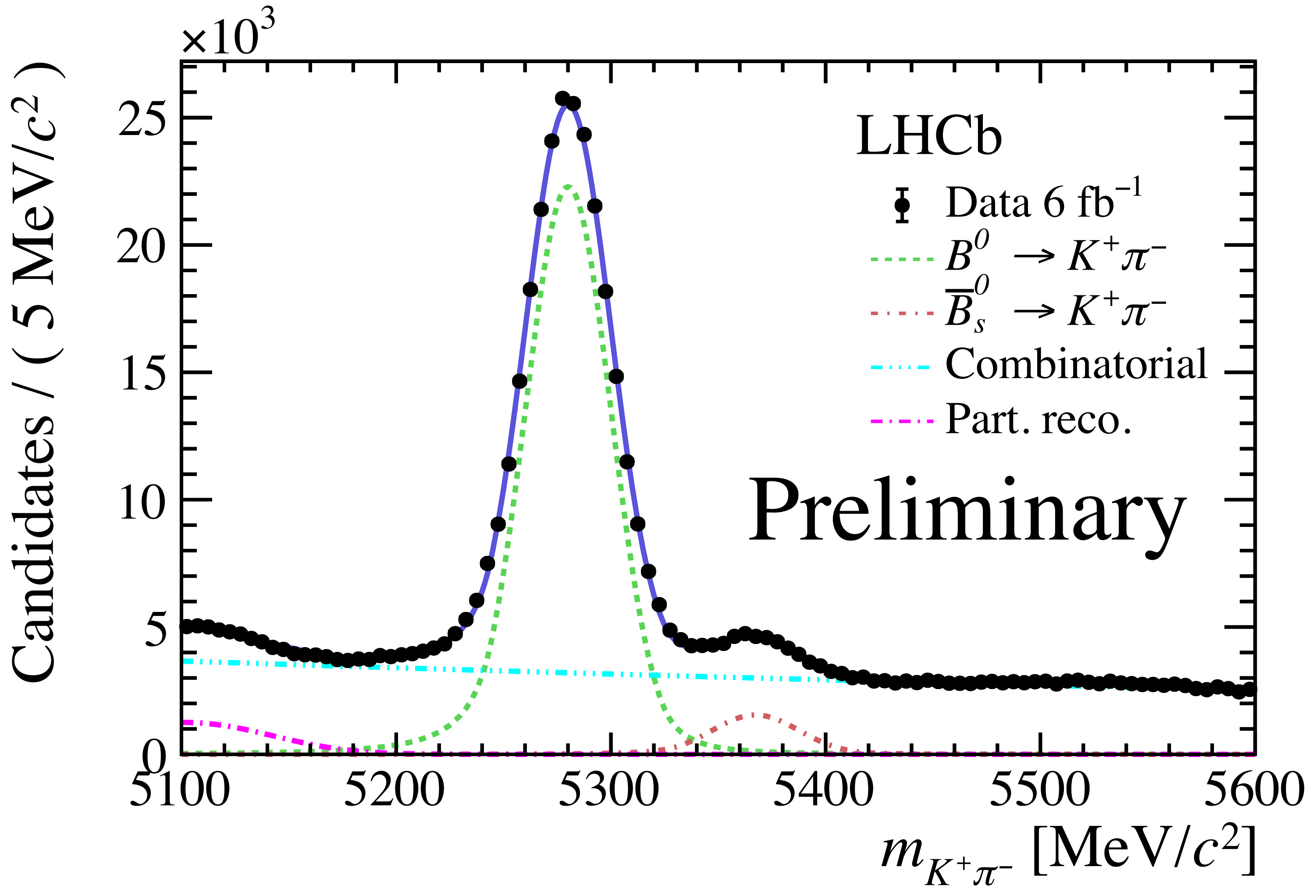
BDT > 0.5

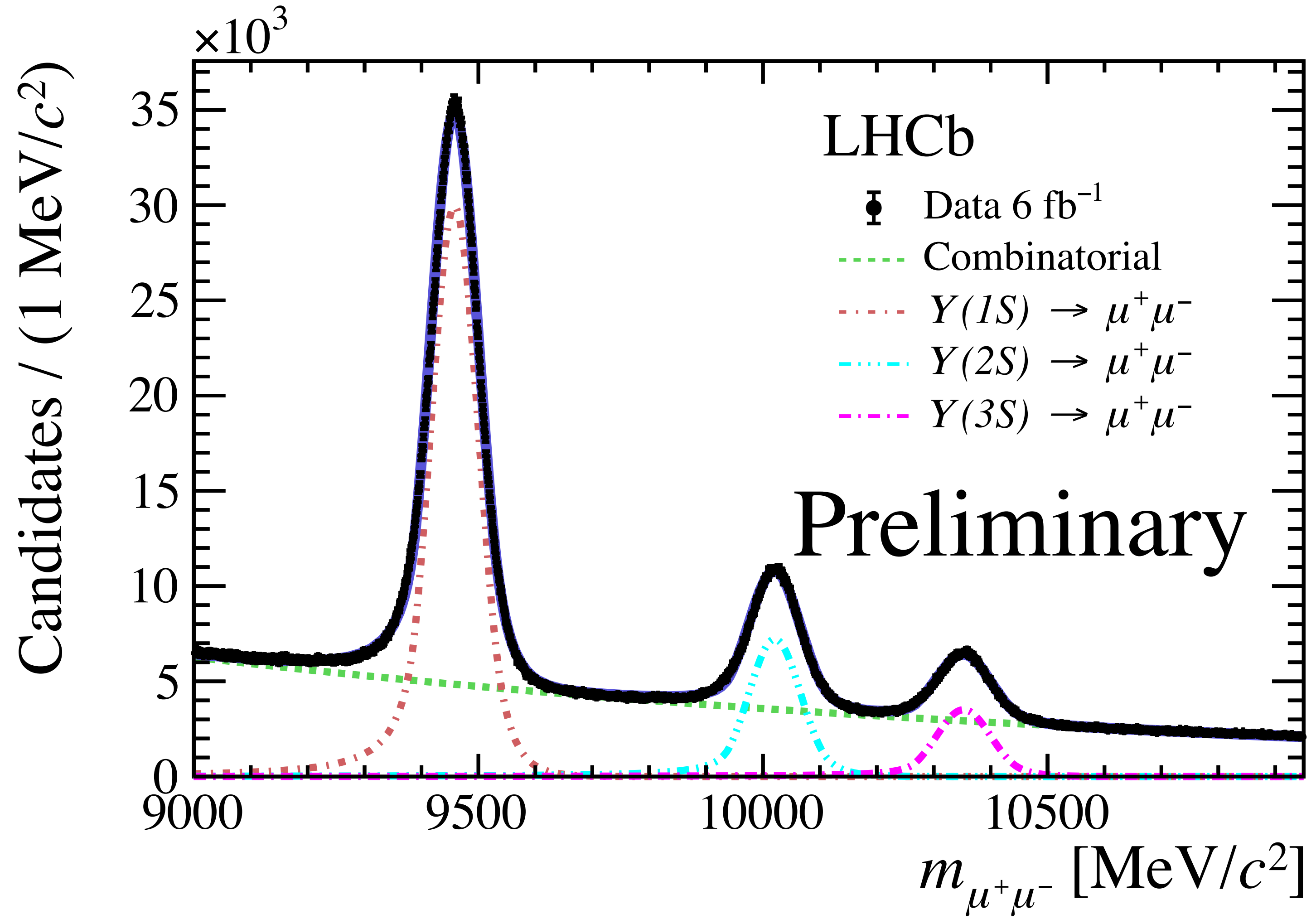
$B \to hh'$	22±1
$B^0 \to \pi\mu\nu$	91±4
$B_s^0 \to K\mu\nu$	23±3
$B \to \pi\mu\mu$	26±3
$\Lambda_b \to p\mu\nu$	4±2
$B_c \to J/\psi\mu\nu$	7.2±0.3

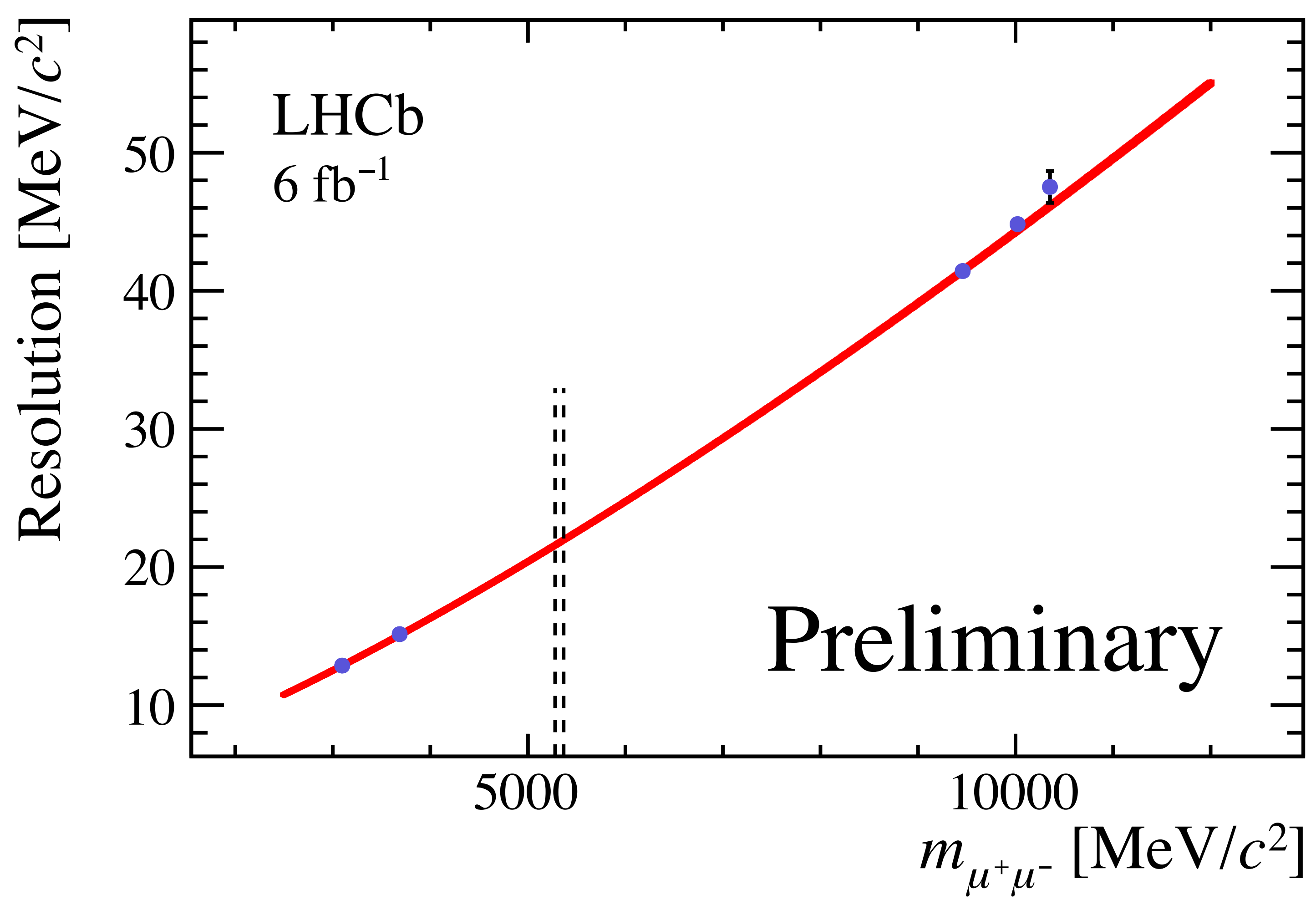


Mass calibration

LHCB-PAPER-2021-007







- Invariant mass signal shape calibrated using data control channels:
  - Mass peak position determined using $B^0 \to K^+\pi^-$ and $B_s^0 \to K^+K^-$
  - Resolution from power law interpolation with dimuon resonances. Mass resolution ~22MeV/c^2

Normalisation

$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-(\gamma)) = \frac{f_{sig}}{f_d}\frac{\varepsilon_{norm}}{\varepsilon_{sig}}\frac{N_{sig}}{N_{norm}}\mathcal{B}(\text{norm}) = \alpha_{sig} N_{sig}$$

- Two normalisation mode: $B^+ \to J/\psi K^+, B^0 \to K^+\pi^-$
- Efficiencies evaluated from simulation and control channels
- Hadronisation fraction from new LHCb combination
  - Uncertainty reduced by factor 2 to ~3%

$$f_s/f_d(13\,\text{TeV}) = 0.254 \pm 0.008$$

$$\frac{f_s/f_d(13\,\text{TeV})}{f_s/f_d(7\,\text{TeV})} = 1.064 \pm 0.008$$

- Expected SM signal events:

147±8 $B^0_s \to \mu^+\mu^-$
16±1 $B^0 \to \mu^+\mu^-$
~3 $B^0_s \to \mu\mu\gamma_{ISR}$ for $m_{\mu\mu}$ >4.9 GeV

LHCb-PAPER-2020-046

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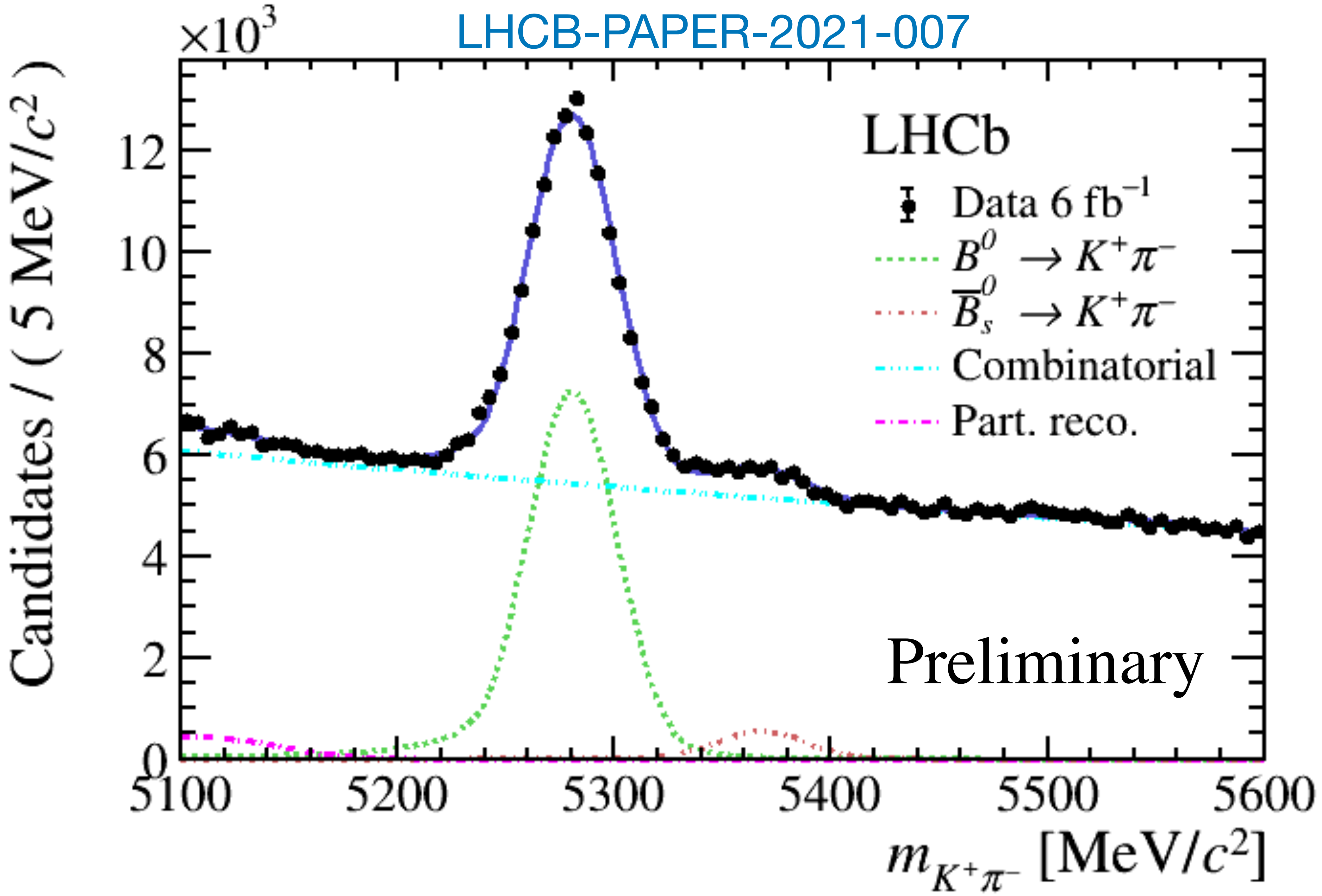
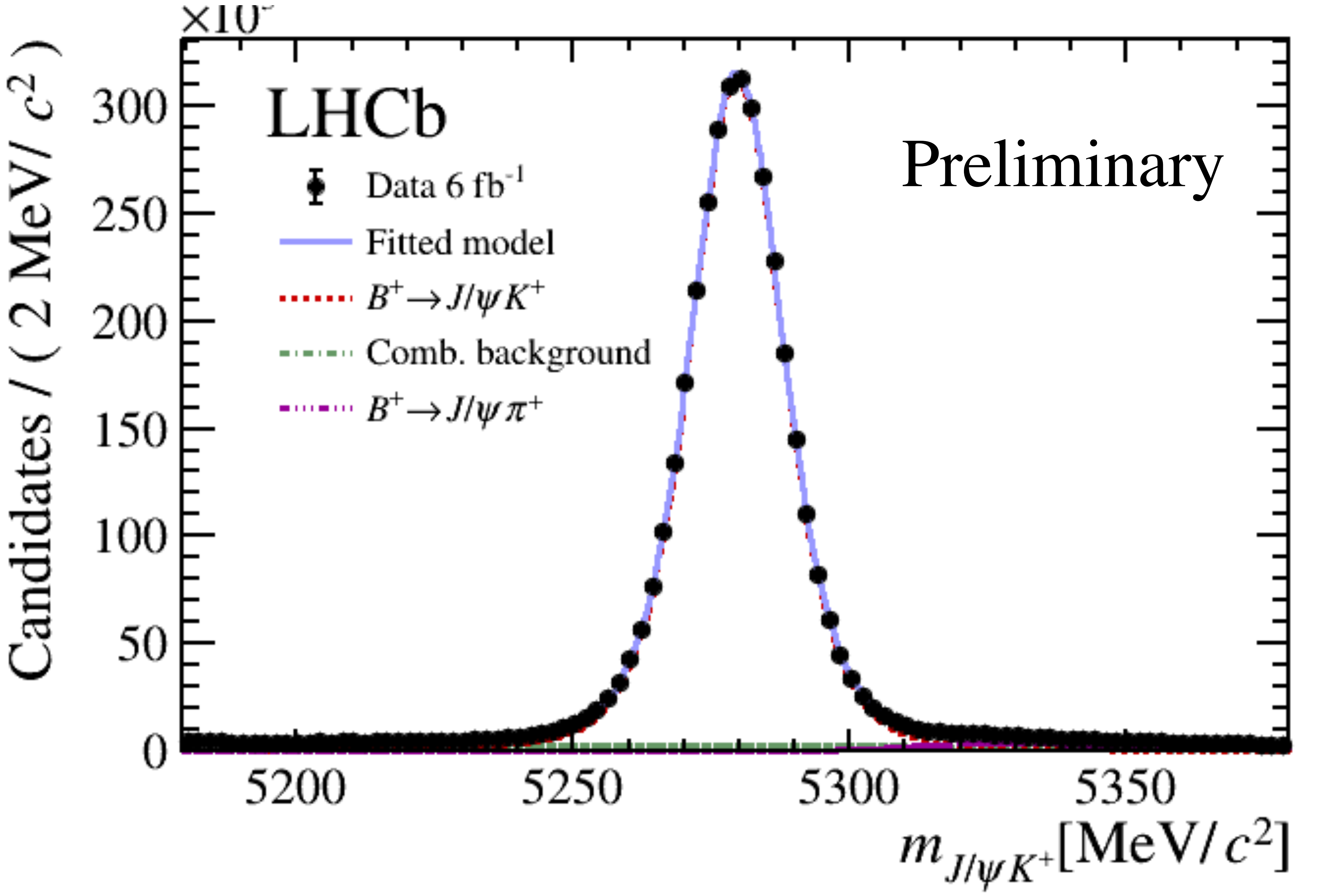
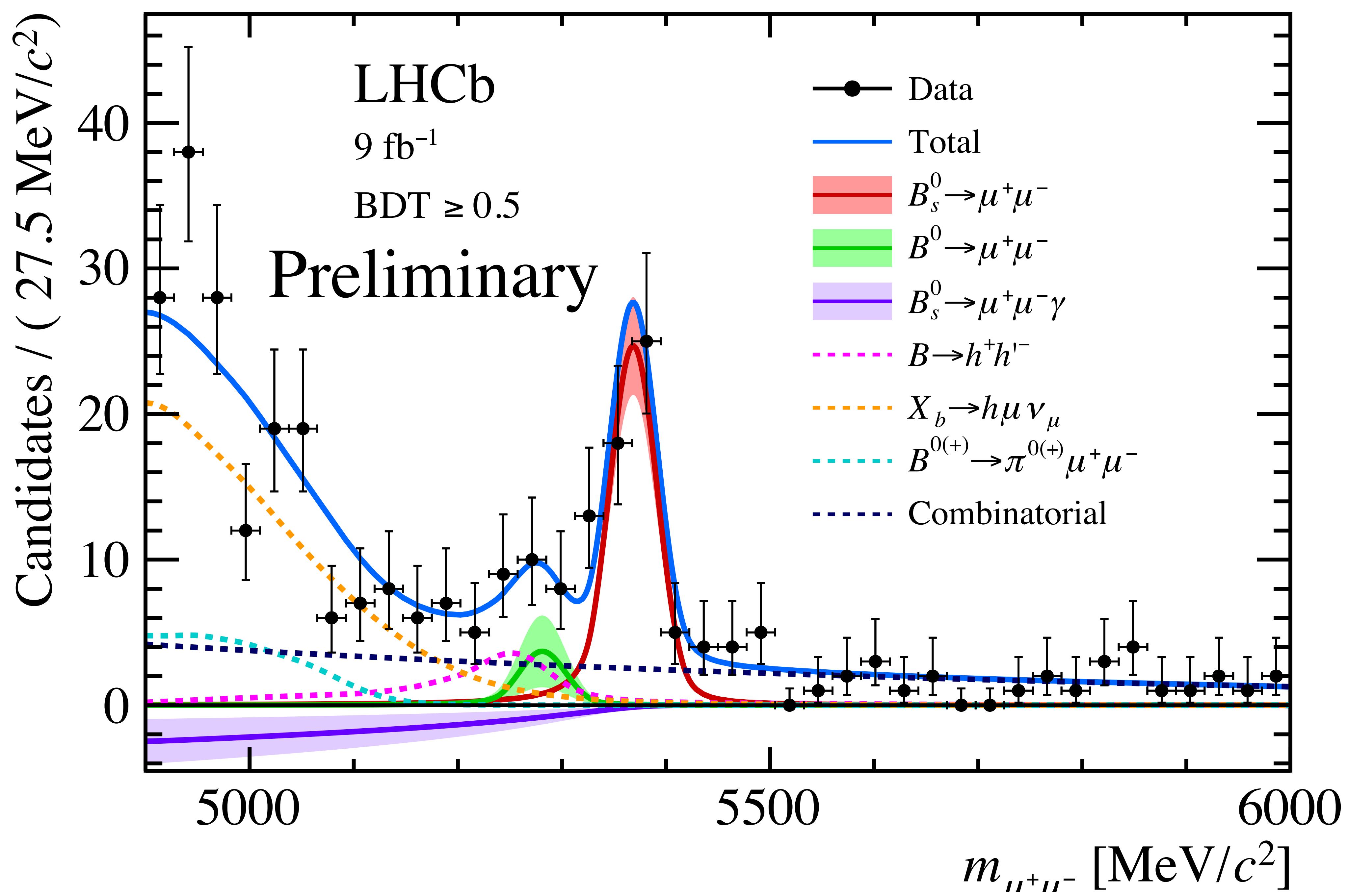


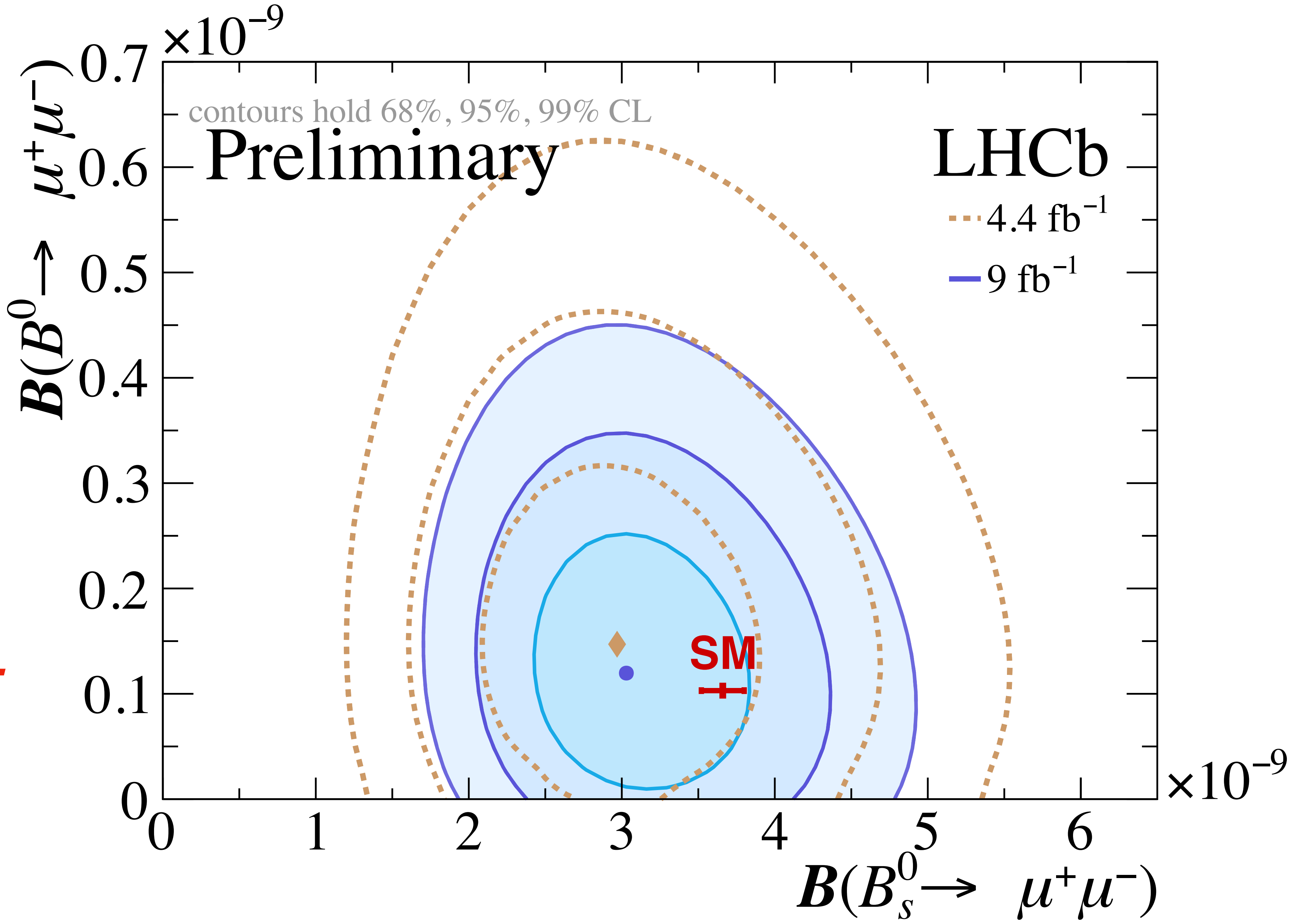


Branching fraction fit

- Unbinned fit on di-muon mass spectra in BDT bins:
  - 5 BDT bins each period (Run1, Run2) considered simultaneously, while bkg dominated bin excluded
  - Signal BFs and combinatorial yield free parameters
- Signal fraction constrained in each BDT bin to expectations
- Exclusive backgrounds yields constrained to their expectations

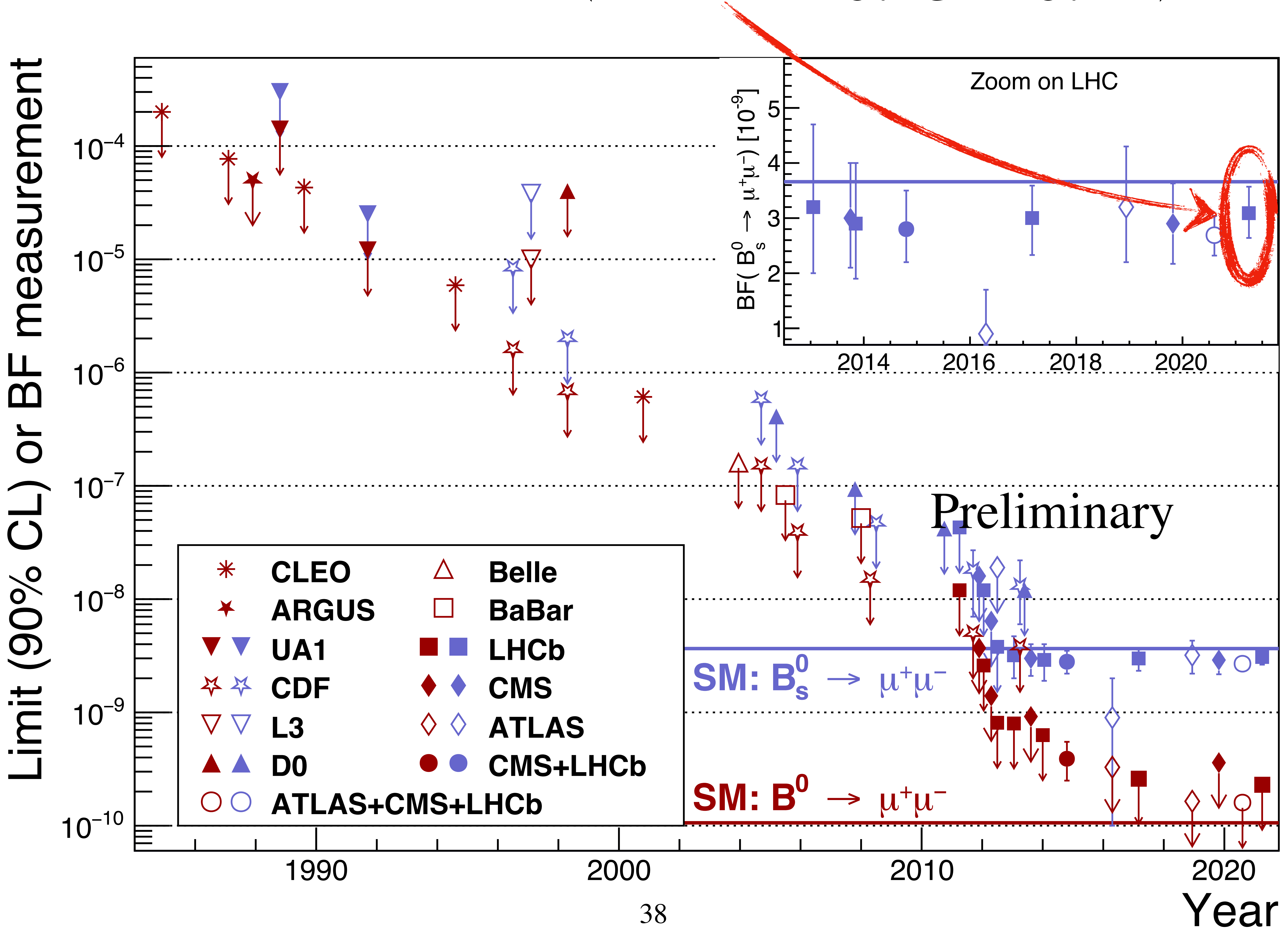
$$\mathscr{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}\right) \times 10^{-9} \quad > 10\sigma$$





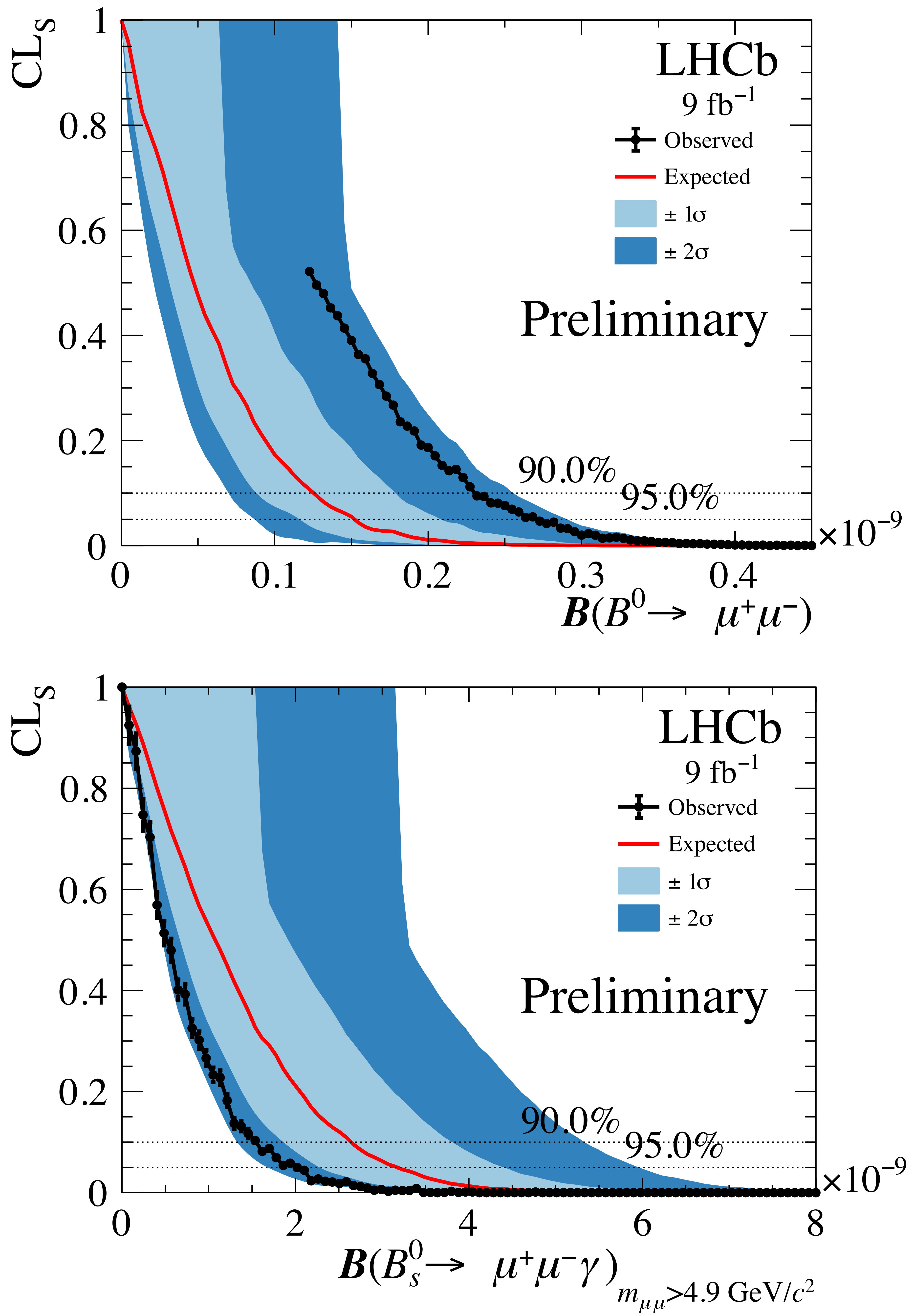
... historical endeavour

$$\mathscr{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}\right) \times 10^{-9}$$



Upper limit estimation

- $B^0 \to \mu\mu$ and $B_s^0 \to \mu\mu\gamma_{\rm ISR}$ not statistically significant
- $\mathrm{CL_S}$ method used to upper limits:
  - $\mathscr{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$ at 95 % CL
  - $\mathscr{B}(B_s^0 \to \mu^+\mu^-\gamma)_{m_{\mu\mu}>4.9\mathrm{GeV}/c^2} < 2.0 \times 10^{-9}$ at 95 % CL
- Compatibility of $\mathscr{B}(B_s^0 \to \mu^+\mu^-\gamma)_{m_{\mu\mu}>4.9\mathrm{GeV}/c^2}$ with background only hypothesis at 1.5σ



Effective lifetime

- Same preselection as BF analysis but looser PID and only two BDT regions are considered
- Fit performed in 2 stages:
  - Invariant mass fit ($m_{\mu\mu} > 5320\text{MeV}/c^2$) to statistically unfold the background
  - Acceptance function modelled on $B_s^0 \to \mu\mu$ simulated decays
- Whole procedure tested on $B^0 \to K^+\pi^-$ and $B_s^0 \to K^+K^-$ decays and compared with previous LHCb analysis:

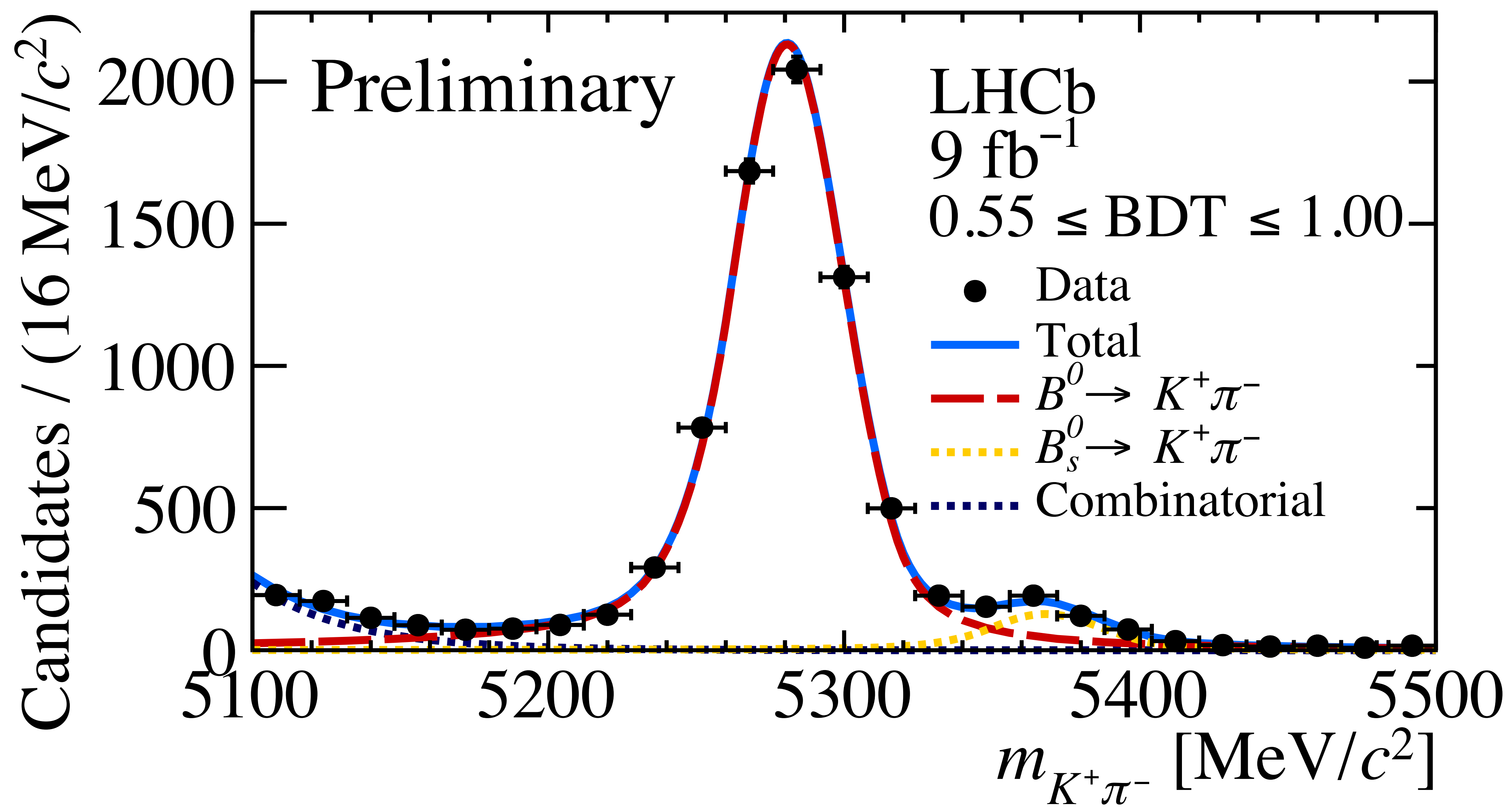
TEST

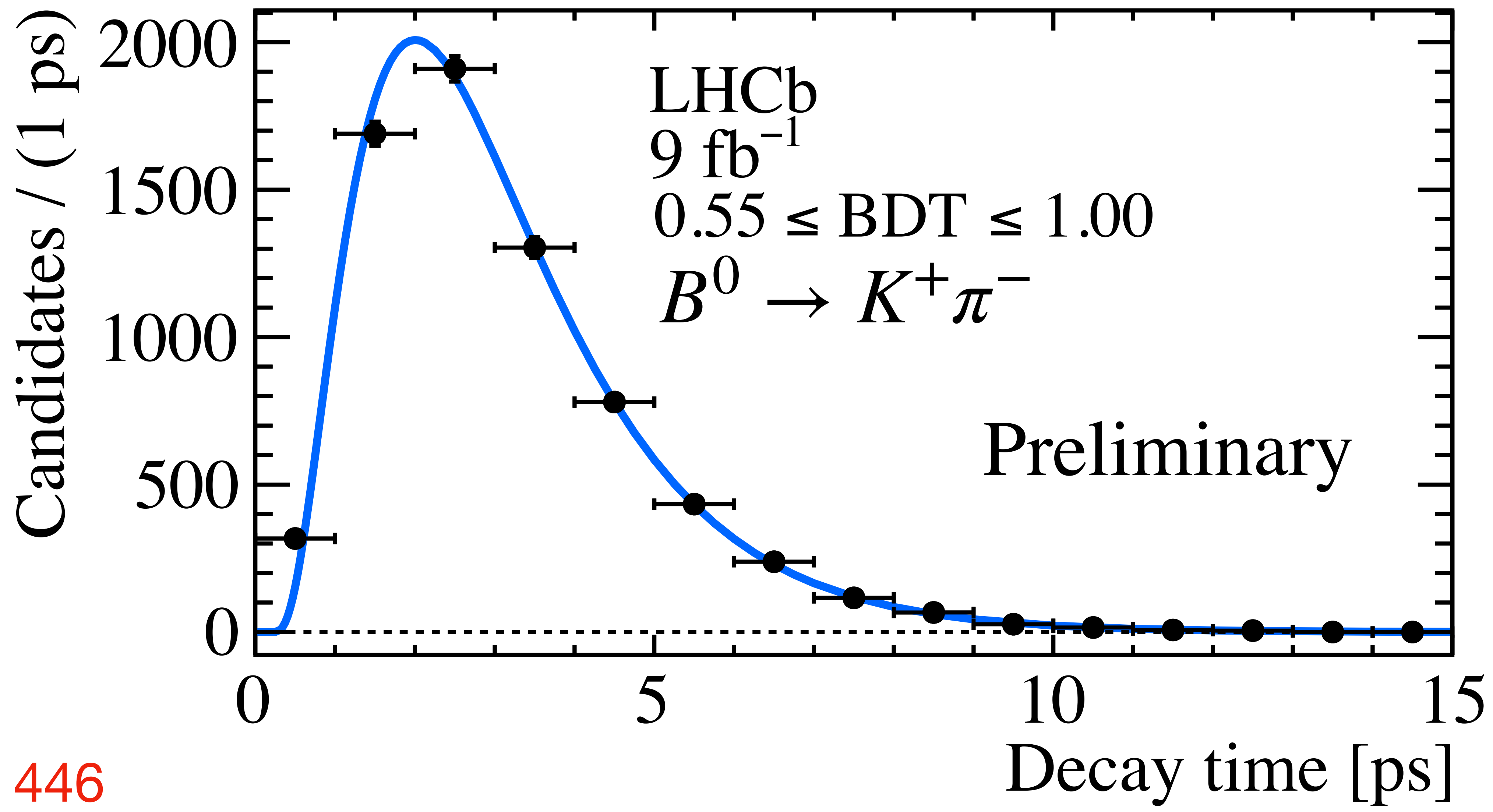
$$\tau_{K^+\pi^-} = 1.512 \pm 0.016\,\text{ps}$$
$$\tau_{K^+K^-} = 1.433 \pm 0.026\,\text{ps}$$

LHCb

$$\tau_{K^+\pi^-} = 1.524 \pm 0.011\,\text{ps}$$
$$\tau_{K^+K^-} = 1.407 \pm 0.016\,\text{ps}$$

Phys. Lett.B736(2014) 446





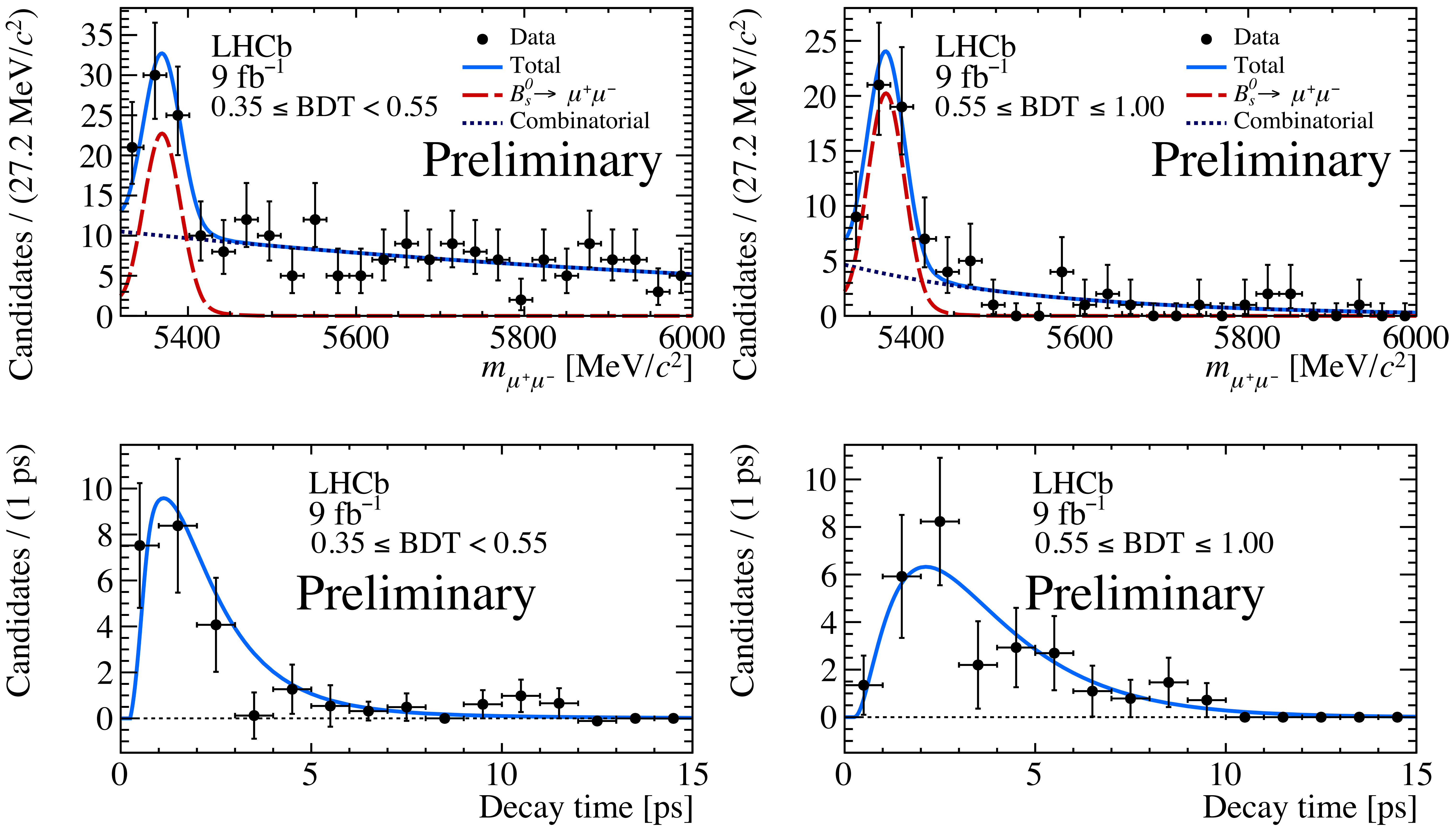
Effective lifetime result

LHCB-PAPER-2021-007

- Fit to $B_s^0 \to \mu\mu$ lifetime gives:

$\tau_{\mu\mu} = (2.07 \pm 0.29 \pm 0.03)$ ps

- Main source of systematics:
  - contamination from $B \to hh'$ and $\Lambda_b \to p\mu\nu$
  - decay time acceptance accuracy
  - mass fit accuracy
- Result compatible at 1.5σ(2.2σ) with SM $A^{\mu\mu}_{\Delta\Gamma} = +1(-1)$



Conclusions

- Purely leptonic B decays offer a rich lab to search for NP effects.
- Update of $B^0_{(s)} \to \mu^+\mu^-$ analysis on full Run1+Run2 dataset presented with improved strategy.
- $\mathscr{B}(B^0_s \to \mu^+\mu^-) = \left(3.09^{\,+0.46\,+0.15}_{\,-0.43\,-0.11}\right) \times 10^{-9}$
    - Uncertainty on $B^0_s \to \mu^+\mu^-$ ~15%, most precise single experiment measurement to date.
    - No evidence of $B^0 \to \mu^+\mu^-$, strong limit on BF
    - First search for $B^0_s \to \mu^+\mu^-\gamma_{ISR}$ process
    - Most precise measurement of $B^0_s \to \mu^+\mu^-$ effective lifetime