CERN seminar – May the 4th, 2020

erc European Research Council

technische universität dortmund

LHCb

Rare decays: from strangeness to beauty

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on behalf of the LHCb Collaboration

An overview of recent LHCb results in rare hadron decays

Why rare decays?

- **Decays forbidden *at the tree level* in the SM, Flavour-Changing Neutral Currents:** $q \to q'\gamma, q \to q'\ell^+\ell^-$
  - Proceed at the **loop level** → very suppressed in the SM
    - Sensitive to **virtual** BSM particles in the loop
  - Precise SM predictions

q=quark
ℓ=lepton
h=hadron

access indirectly high mass scales!

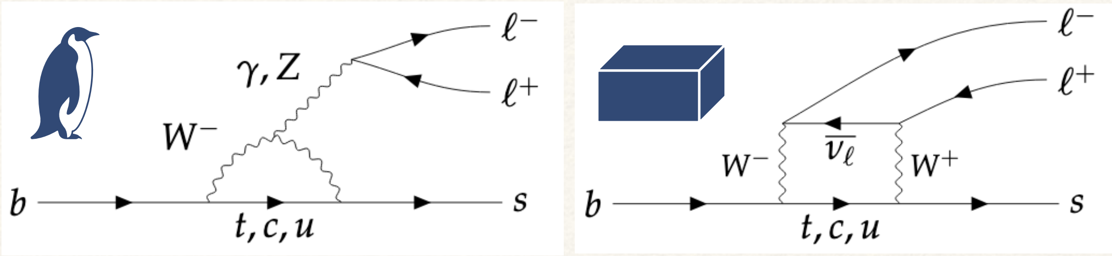
- **Decays forbidden in the SM (or beyond experimental reach):** $q \to q'e^+\mu^-, h \to h'\ell^+\ell^+, \ldots$
  - Observation would be a clear sign of BSM

Rare decays allow for model-independent BSM searches.

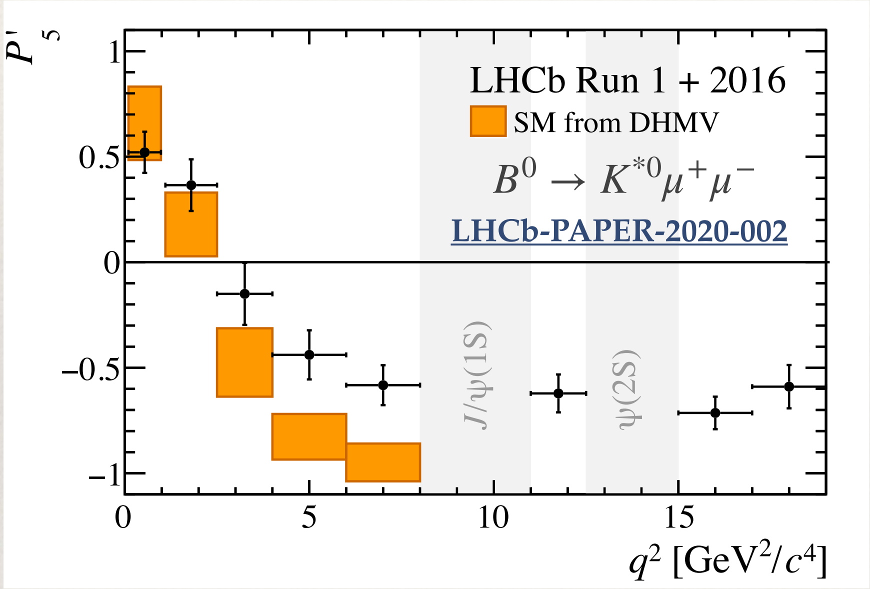
- Historically drove some benchmarks of particle physics
  - 1970s: $K_L \to \mu^+\mu^-$ is suppressed: GIM mechanism, indirect evidence for charm quark
  - 2010s: $B_s^0 \to \mu^+\mu^-$: rate comparable to the SM, exclude a large BSM range
  - …

Recent anomalies in rare decays

- A number of tensions with the SM in $b \to s\ell^+\ell^-$ transitions:



- **Differential branching fractions, angular observables…**
  - For an overview, see the recent CERN seminar by Eluned Smith



- **Lepton-flavour universality (LFU):** all leptons ($e^\pm, \mu^\pm, \tau^\pm$) have the same couplings to the SM gauge bosons
  - **Hints of deviations from LFU:** R_K, R_{K^*}
  - See CERN seminar by Paula Alvarez Cartelle

Should we get excited?

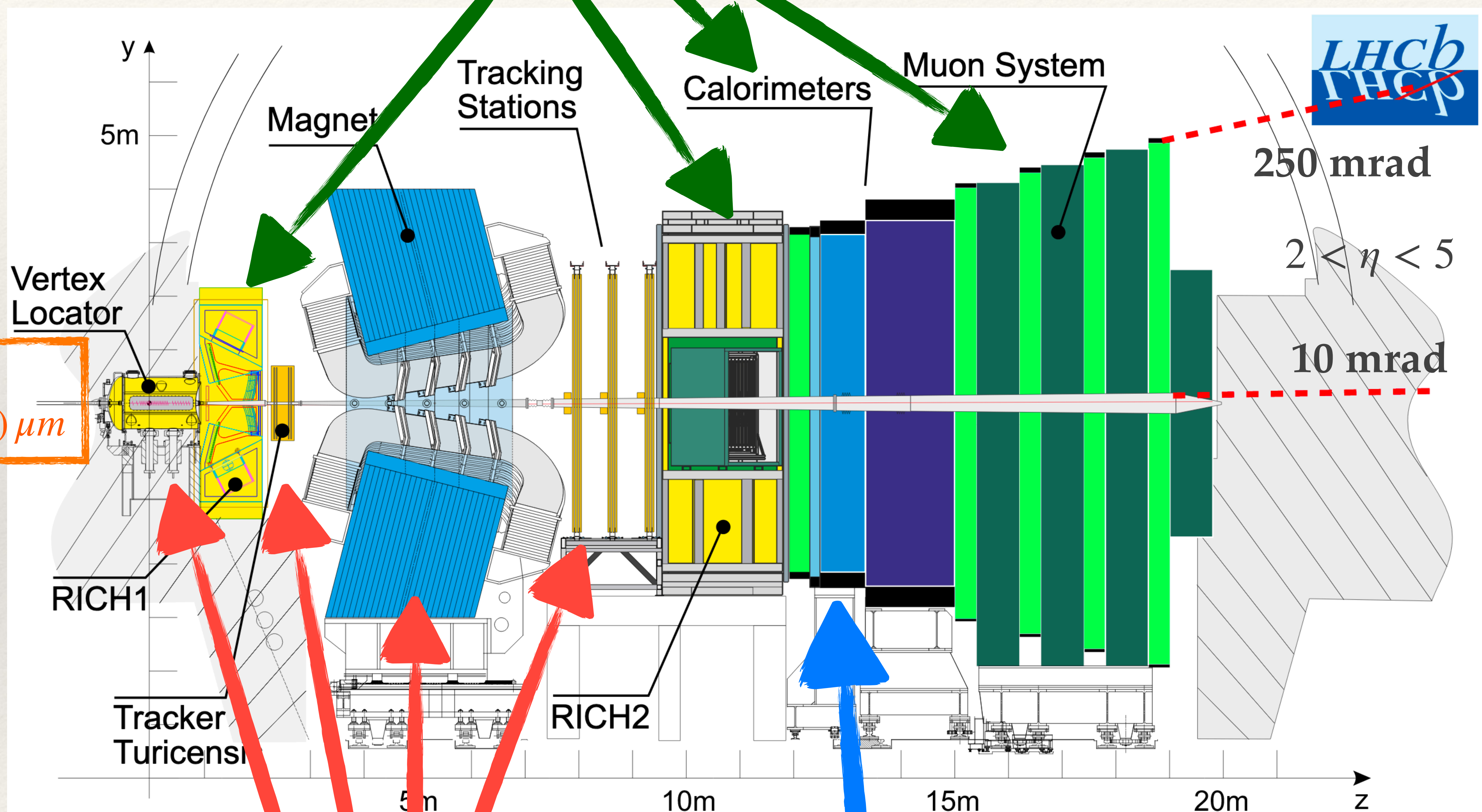
- We don't know yet: most of results are dominated by the **statistical uncertainties**

- Two pathways towards clarifying the situation:
  - Update of hot $b \to s\ell^+\ell^-$ results with a larger dataset
    - $B^0_{(s)} \to \mu^+\mu^-$, $R_{K^{(*)}}$, … with the full LHCb dataset are in preparation.
  - **Explore new horizons: today**

- We look for **complementary** observables:
  - Study $s \to d\ell^+\ell^-$, $c \to u\ell^+\ell^-$ transitions: are there deviations in **charm** and **strange** decays?
  - Explore new final states of $b \to s\ell^+\ell^-$: modes with **electrons and taus**, **baryonic** modes, …
  - Search for **decays forbidden in the SM**

The LHCb detector @ the LHC

Particle identification (PID)
$\sim 97\,\%$ (μ, e) ID rate 1-3% pion misID;
good separation of hadrons $\pi/K/p$



VELO
$\sigma_{IP} = (15 + 29/p_T)\,\mu m$

tracking system
$\sigma_p/p = 0.4...0.6\,\%$

ECAL
$\sigma_E/E \sim 10\,\%/\sqrt{E} \oplus 1\,\%$

LHCb datasets

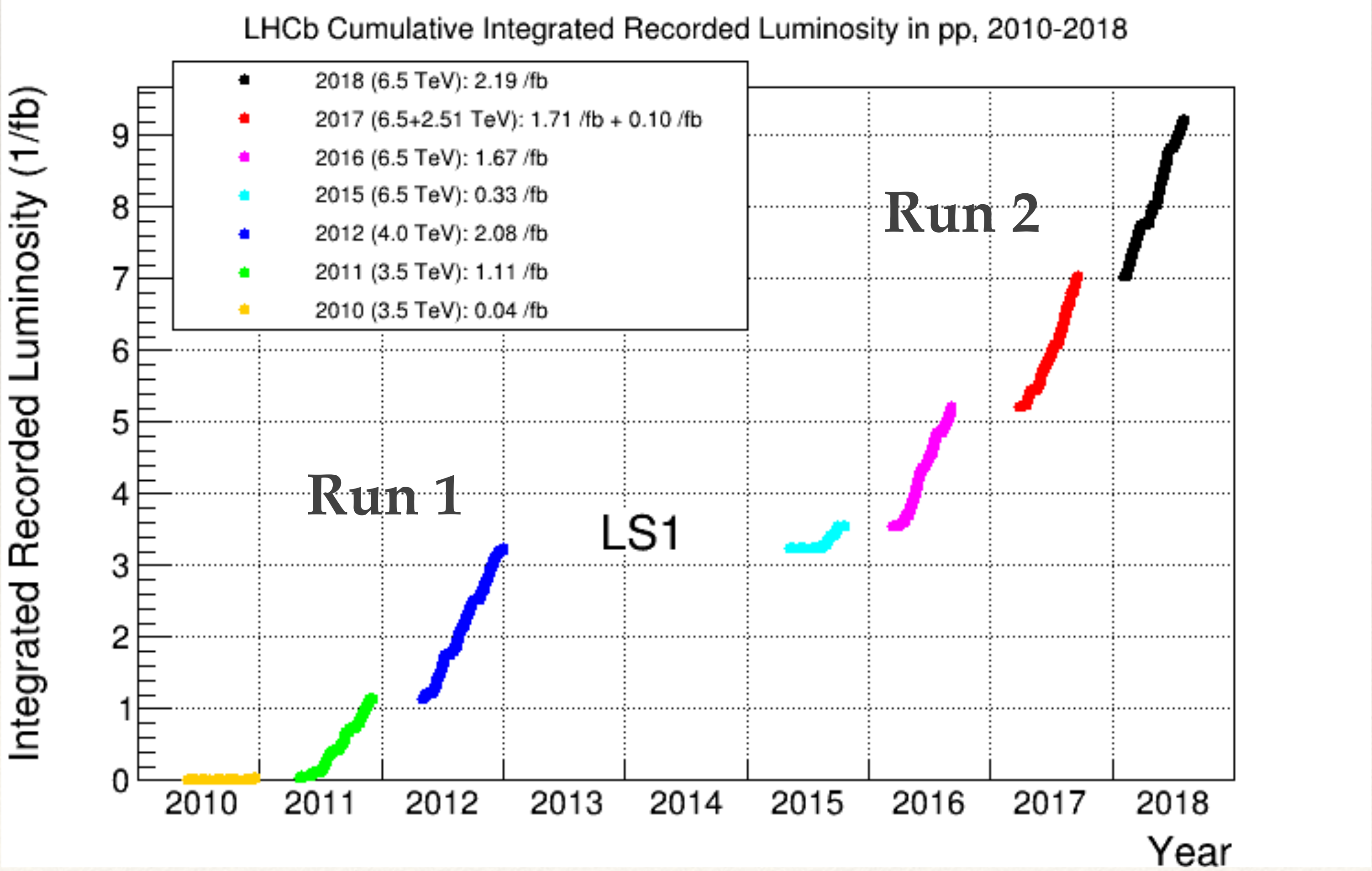
PRL 118 (2017) 052002
JHEP 05 (2017) 074
and other

- Large production cross-sections of various hadrons at LHCb:
  - $\sigma(pp \to b\bar{b}X) \approx 140\mu b$
  - $\sigma(pp \to c\bar{c}X) \approx 2400\mu b$
  - $\sigma(pp \to s\bar{s}X) \sim 1b$

(at 13 TeV)

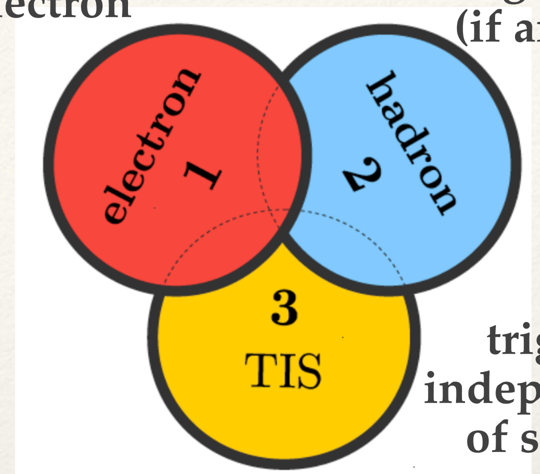
large boost → displacement from the primary vertex

- Collected 9 fb^{-1} of data at 7, 8 and 13 TeV
  - Thanks to CERN accelerator team for the excellent LHC performance!

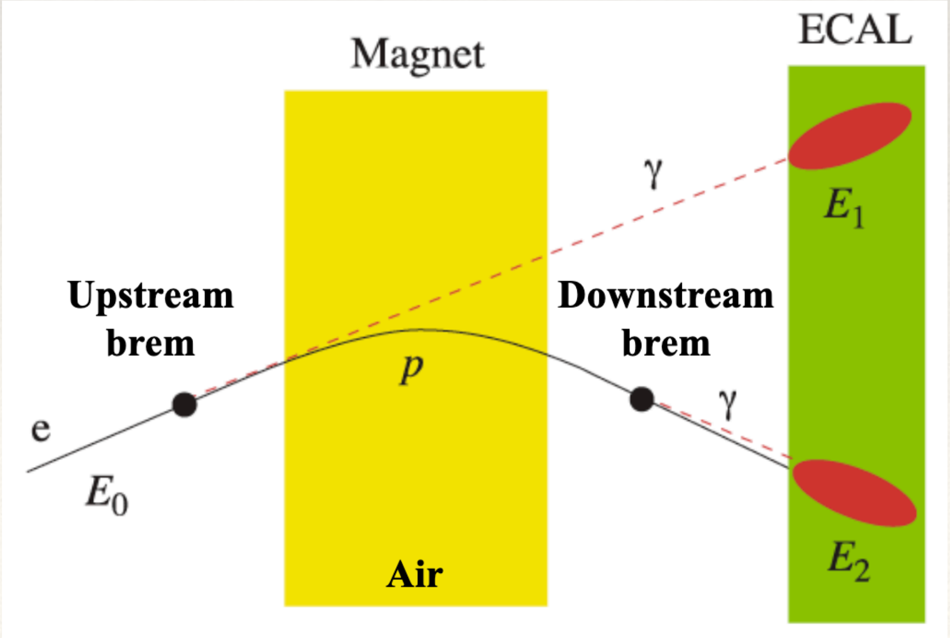


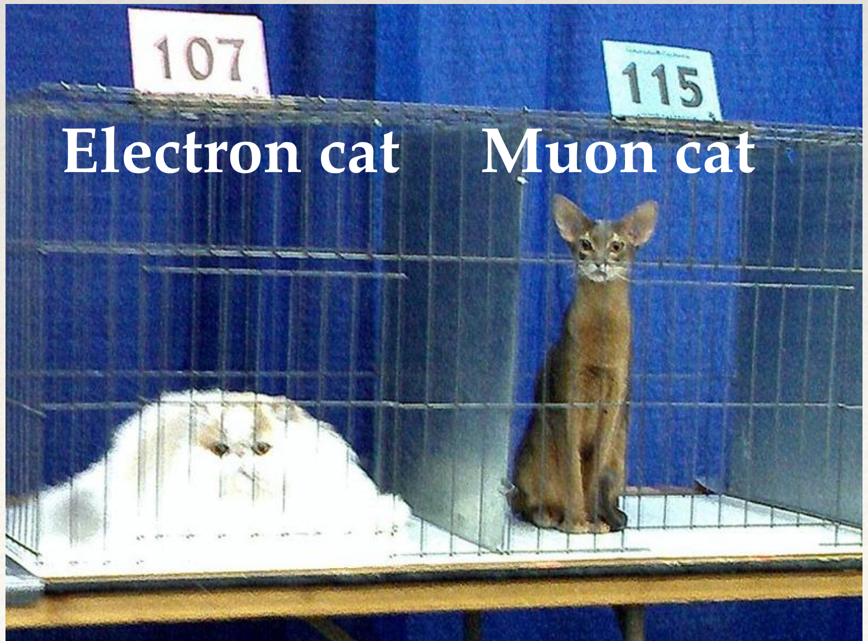
Challenges with electrons

- **Hardware** trigger:
  - efficient for final states **with muons** (~90 %)
  - a bottleneck for final states *without* muons
    - calorimeter has a high occupancy, tight thresholds
  - final states **with electrons** can be triggered in several ways:



- **Electrons** emit a large amount of **bremsstrahlung** in interactions with the detector material
  - If a photon is emitted *before the magnet*:
    - electron momentum measured *after* bremsstrahlung;
    - photon ends up in a *different* ECAL cell
  - dedicated procedure to search for these photons and correct the electron momenta
  - not a perfect correction, **affects the resolution**





Shopping list for today

- **Meson decays to two leptons**
  - $B^0_{(s)} \to e^+e^-$: arXiv:2003.03999
  - $K_S \to \mu^+\mu^-$: arXiv:2001.10354

presented for the first time!

thanks to organisers for opportunity to present these results!

- **Lepton universality tests**
  - R_{pK} with $\Lambda^0_b \to pK^-\ell^+\ell^-$ decays: arXiv:1912.08139

- **Searches for other suppressed or forbidden decays**
  - $B^+ \to K^+\mu^-\tau^+$ from B^*_{s2} decays: arXiv:2003.04352
  - 25 $D_{(s)} \to h\ell\ell$ modes: LHCb-PAPER-2020-007, **NEW**

presented for the first time!

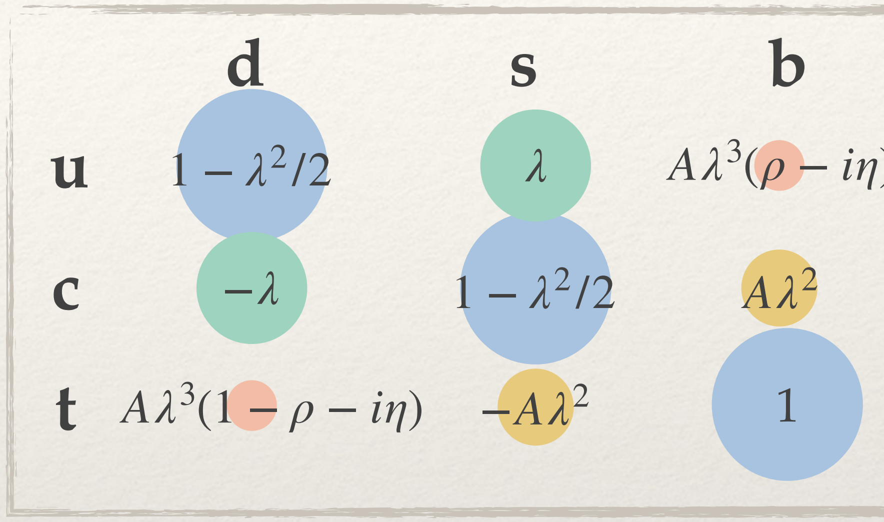
presented for the first time!

Meson decays to two leptons

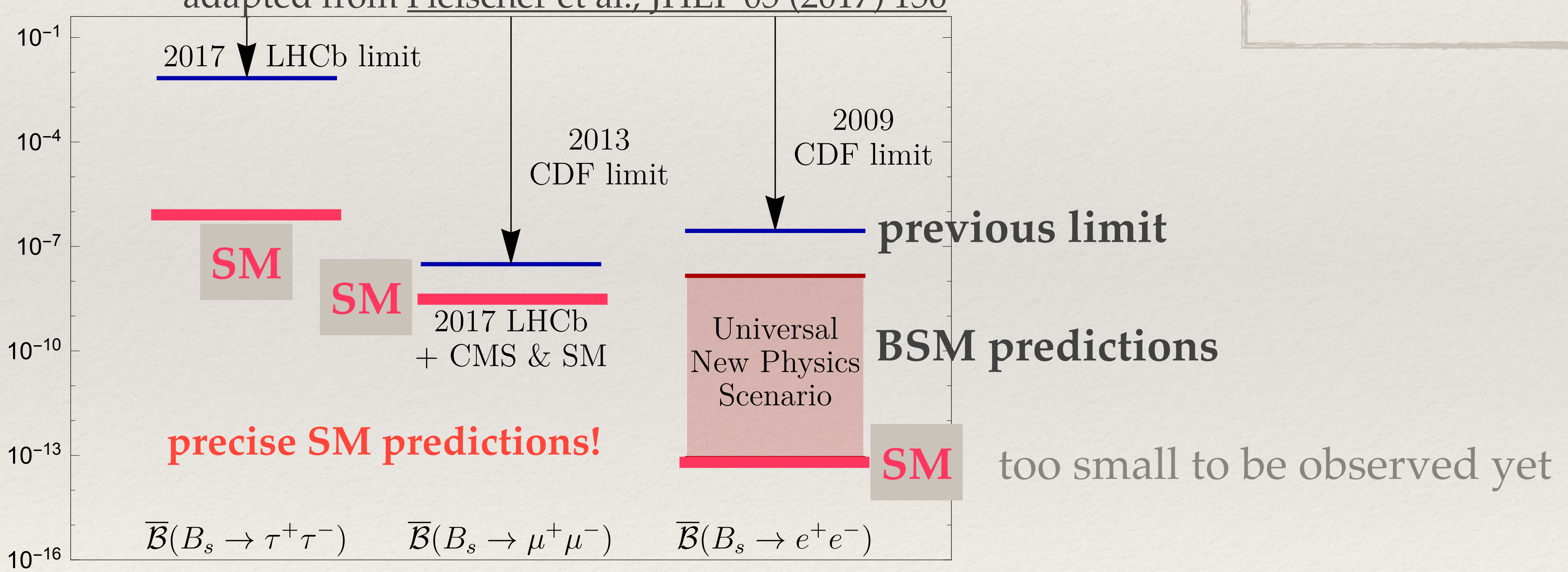
Why $h^0 \to \ell^+\ell^-$?

LHCb-PAPER-2020-001
arXiv:2003.03999
accepted by PRL

- FCNC, very rare: sensitive to BSM contributions
  - **CKM suppression**: $\mathcal{B}(B^0 \to \ell^+\ell^-) < \mathcal{B}(B^0_s \to \ell^+\ell^-)$ due to $|V_{td}| < |V_{ts}|$
  - **GIM suppression** for strange and charm decays
  - Helicity-suppressed
    - suppression largest for $\ell^\pm = e^\pm$
    - $\mathcal{B}(B^0_s \to e^+e^-) \sim \mathcal{B}(B^0_s \to \mu^+\mu^-) \times (m_e/m_\mu)^2$



adapted from Fleischer et al., JHEP 05 (2017) 156



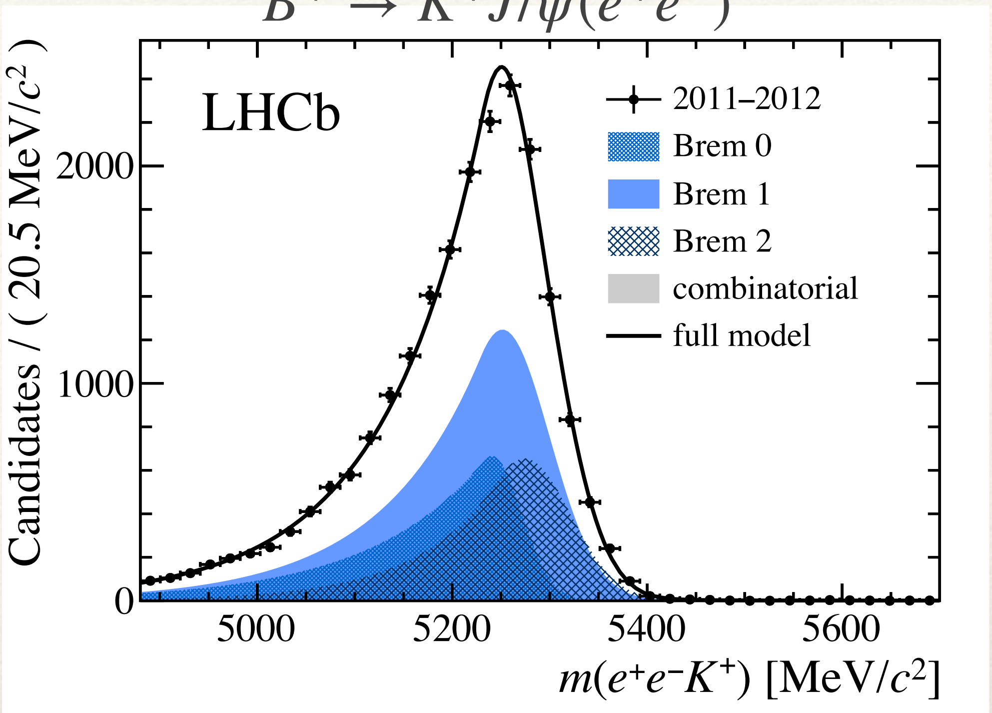
- LHC experiments searched for $B^0_{(s)} \to \mu^+\mu^-$ and $B^0_{(s)} \to \tau^+\tau^-$, this is the first search for $B_{(s)} \to e^+e^-$ at LHC

Dataset:
2011-2016
(5 fb^{-1})

Bremsstrahlung

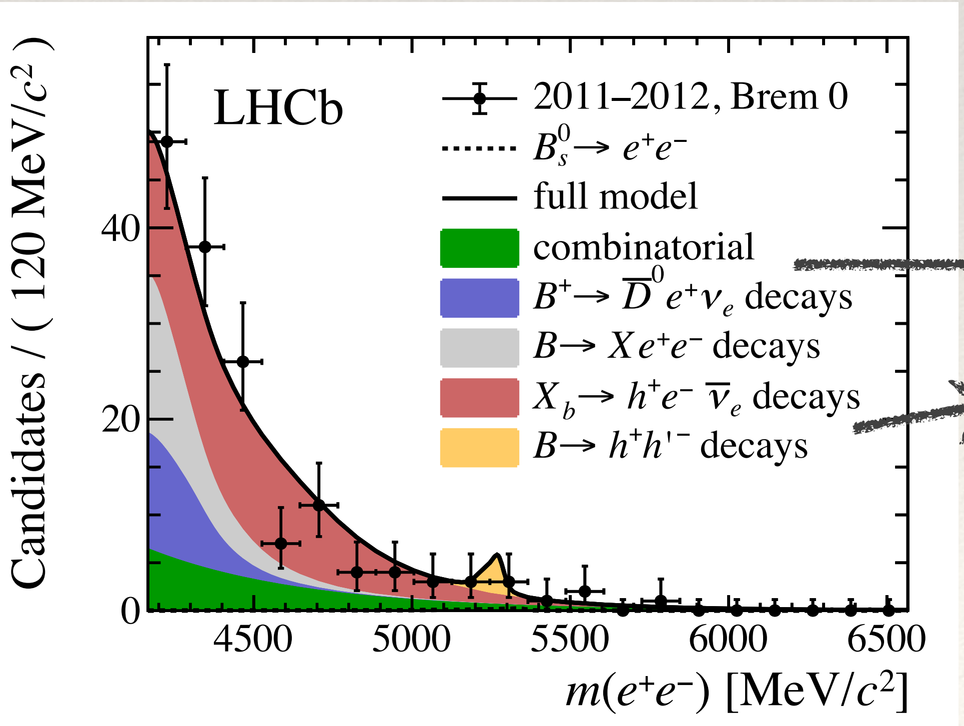
- Mass resolution depends on the **number of recovered bremsstrahlung photons**
  - studied with $B^+ \to K^+ J/\psi(e^+e^-)$ data:
- However, bremsstrahlung recovery **improves the electron ID**
  - only electrons emit a significant amount of radiation

$B^+ \to K^+ J/\psi(e^+e^-)$



Different background composition between the photon recovery categories:

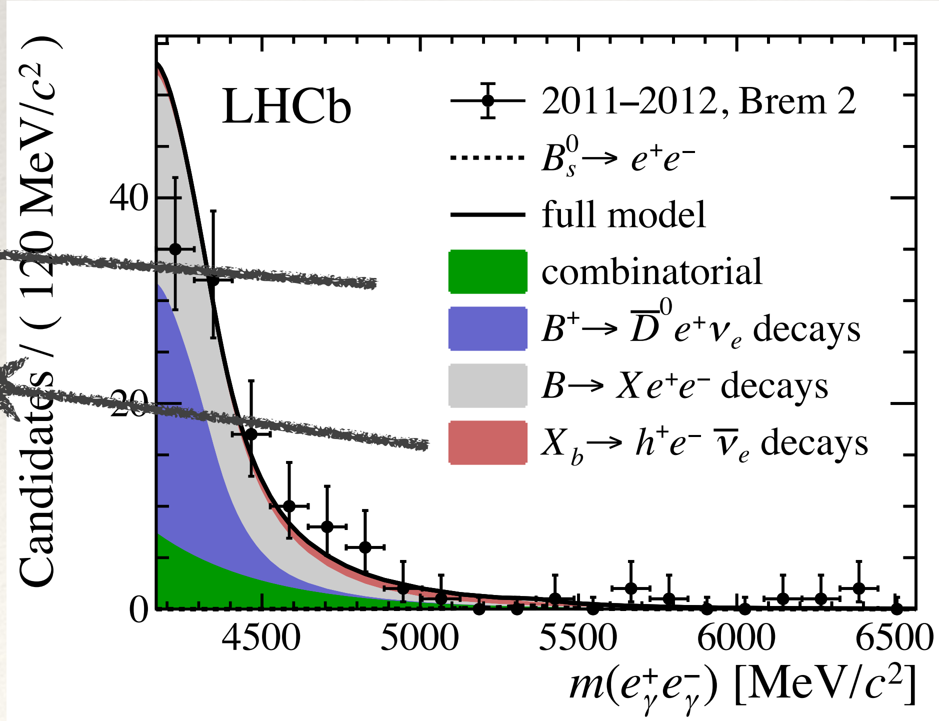
No recovered photons



suppressed by MVA

suppressed by particle ID

Photons recovered for both electrons



Search for $B^0_{(s)} \to e^+e^-$: results

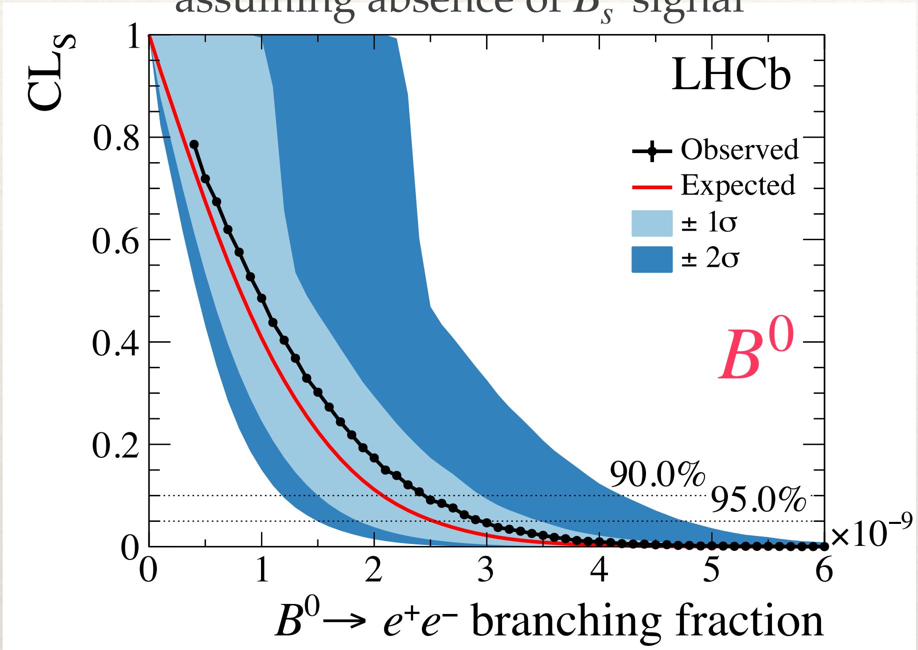
LHCb-PAPER-2020-001
arXiv:2003.03999
accepted by PRL

- $B^+ \to K^+ J/\psi(e^+e^-)$ taken as a normalisation channel
  - cancellation of uncertainties due to electron reconstruction
- No significant signal; limits set @ 90%CL:

2017-2018 data yet to be analysed!

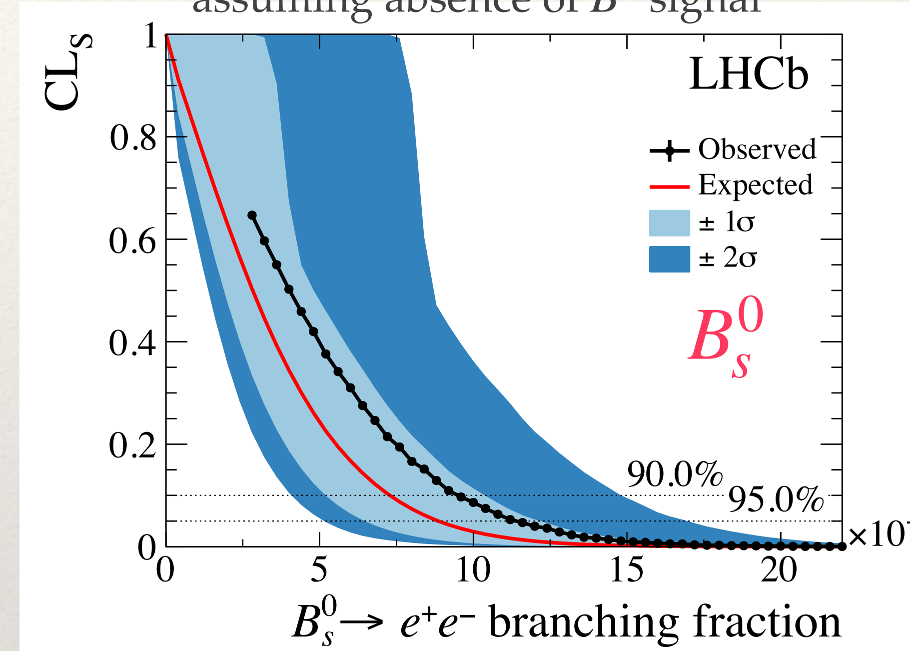
$$\mathscr{B}(B^0 \to e^+e^-) < 2.5 \times 10^{-9}$$

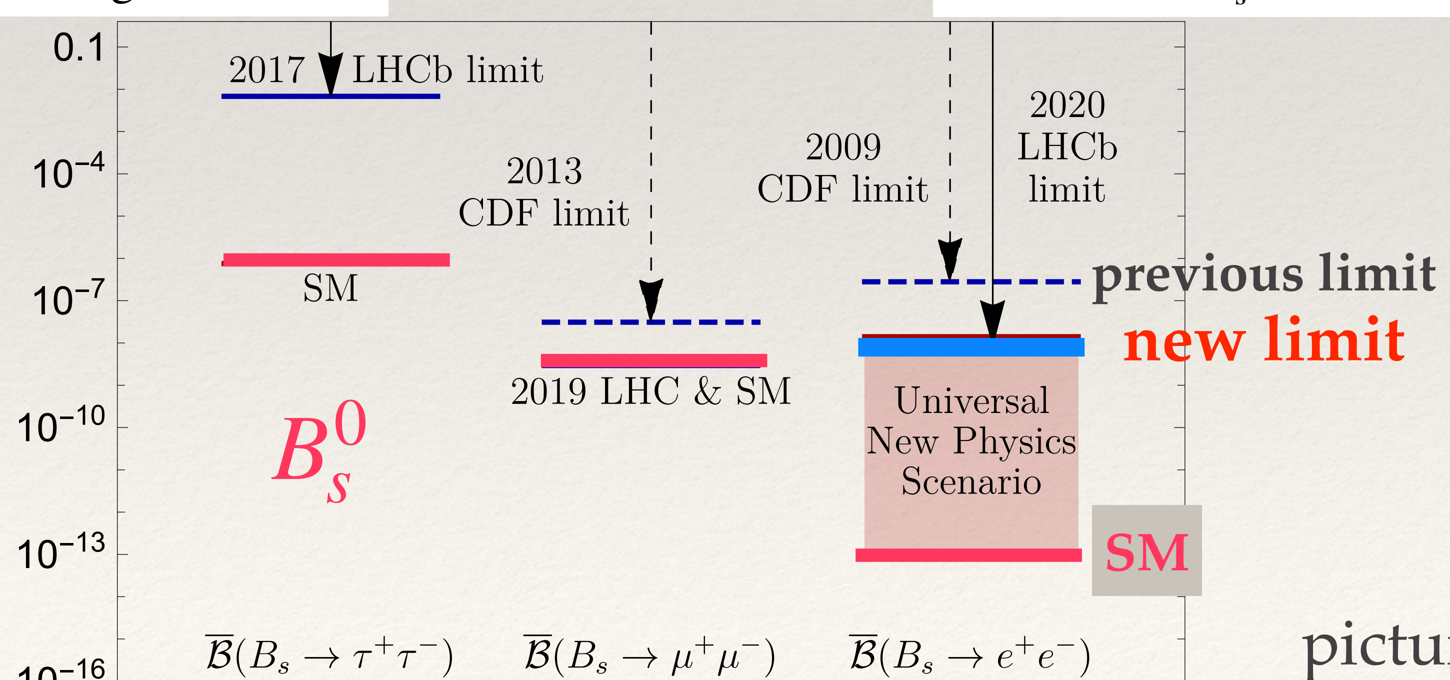
assuming absence of B^0_s signal



$$\mathscr{B}(B^0_s \to e^+e^-) < 9.4 \times 10^{-9}$$

assuming absence of B^0 signal





adapted from Fleischer et al., JHEP 05 (2017) 156

x30 improvement!

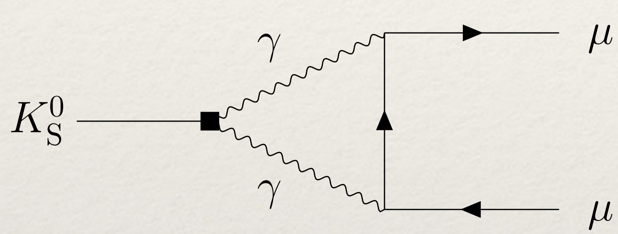
picture is similar for B^0.

Search for $K_S \to \mu^+\mu^-$

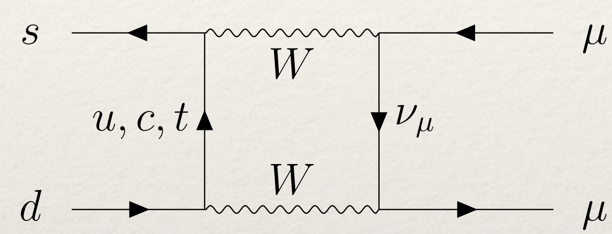
LHCb-PAPER-2019-038
arXiv:2001.10354

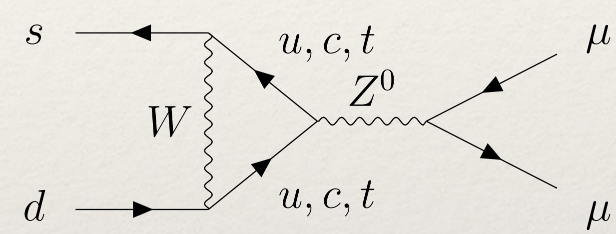
- A 'little sister' of the $K_L \to \mu^+\mu^-$ ($\mathcal{B} \sim 6 \times 10^{-9}$) which revolutionised particle physics
- Has additional CP suppression: SM prediction $\mathcal{B} \sim 5 \times 10^{-12}$ hep-ph/0311084
  - Previous limit: LHCb Run 1, $\mathcal{B} < 0.8 \times 10^{-9}$ @ 90 % CL Eur. Phys. J. C77 (2017) 678

'long-distance'



'short-distance'

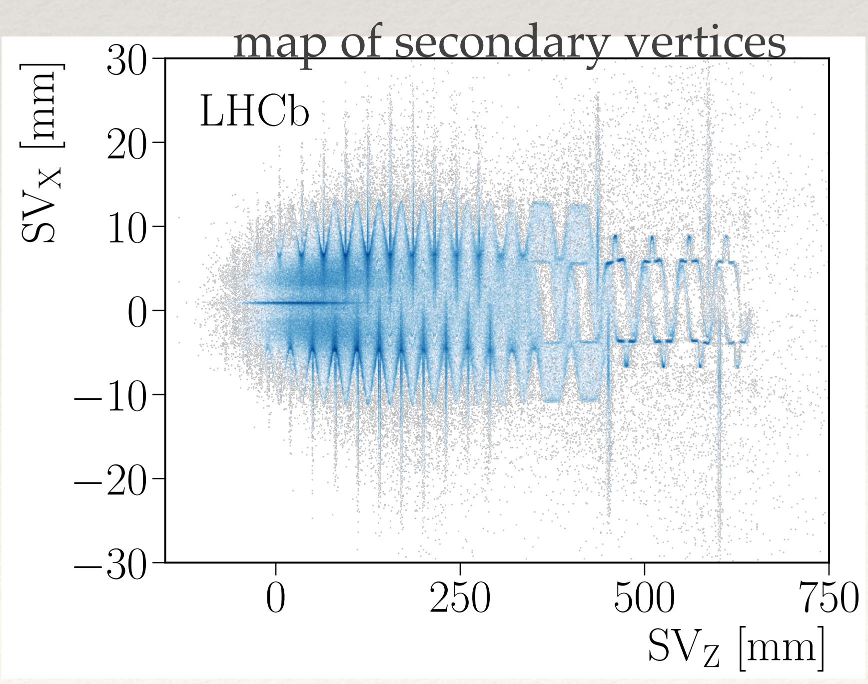




- **Soft kinematics:** need dedicated triggers and reconstruction
  - In place since 2016: efficiency *an order of magnitude* larger than in Run 1
  - Still limited by the hardware trigger

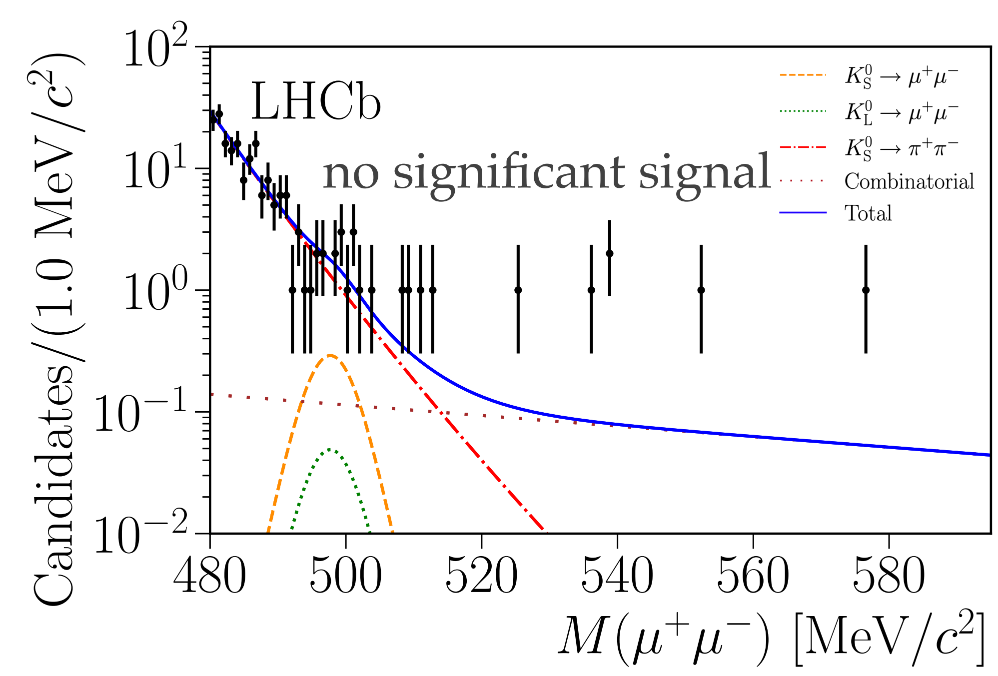
Dataset: 2016-2018 (5.5 fb^{-1})

- Consider only K_S decaying inside VELO (22%)
  - Removed backgrounds from inelastic interactions with the VELO material
    - Displaced vertices mimicking signal



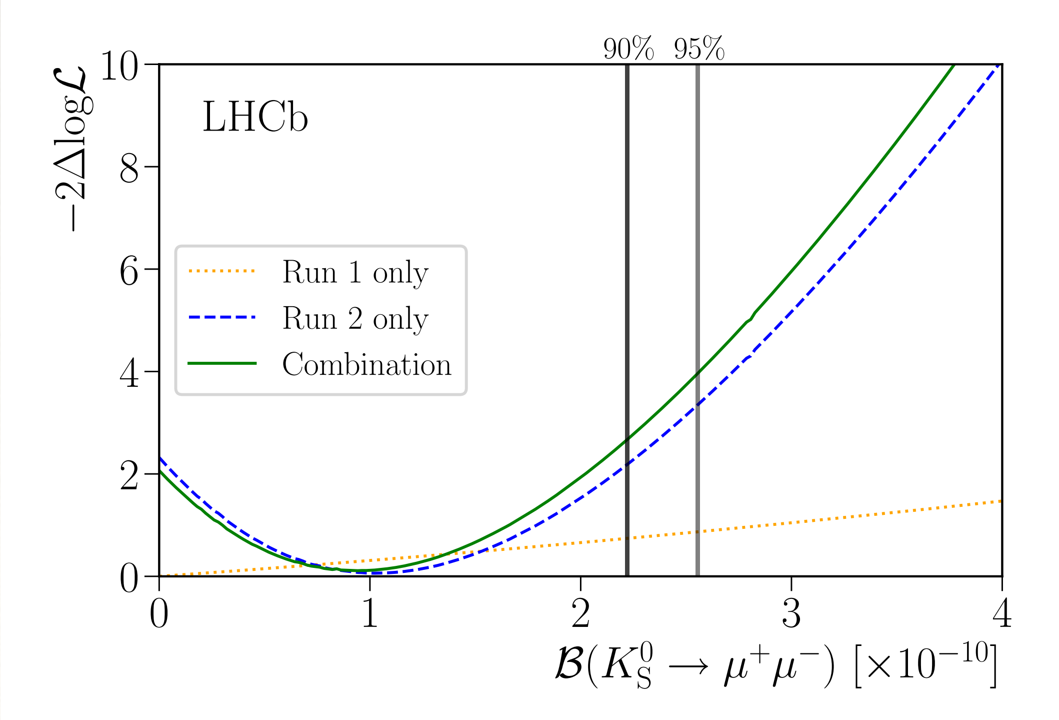
Search for $K_S \to \mu^+\mu^-$

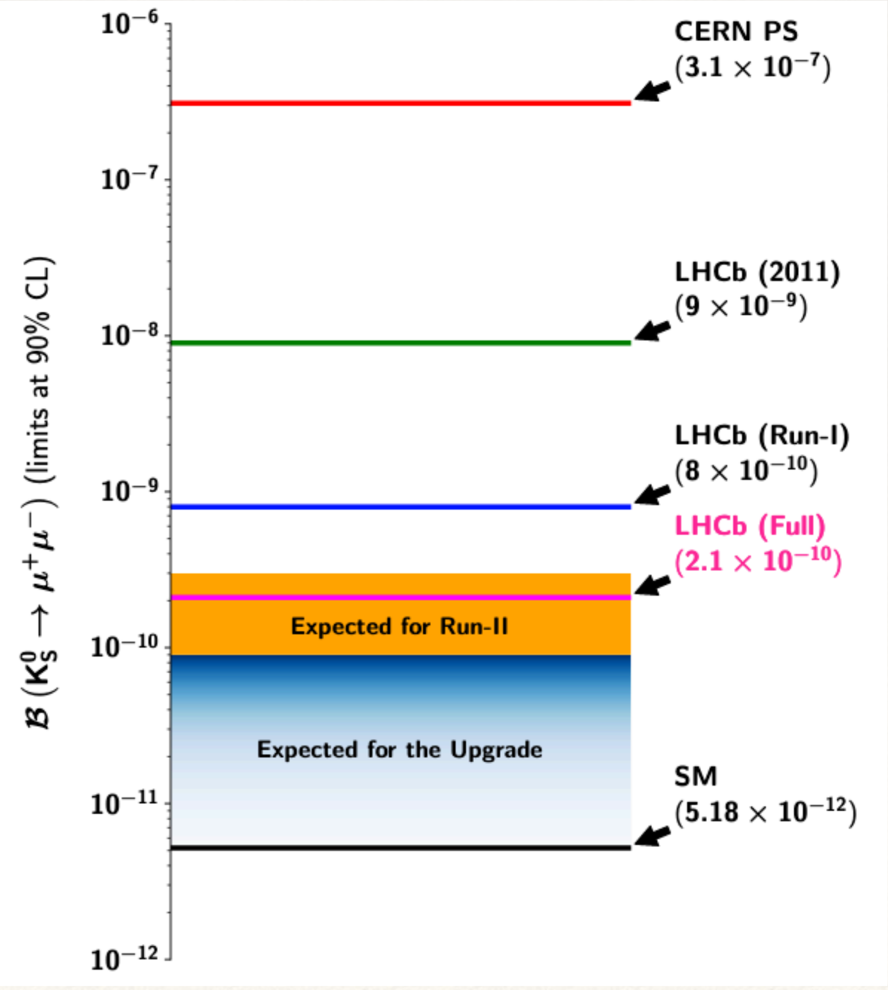
- Normalised to $K_S \to \pi^+\pi^-$
- $K_S \to \pi^+\pi^-$ also is a dominant misidentification background: branching fraction is more than *ten orders of magnitude* larger!
- Background from $K_L \to \mu^+\mu^-$ is suppressed due to its long lifetime
  - well-known rate



- Limit set, combined with LHCb Run 1 result:

$$\mathscr{B}(K_S \to \mu^+\mu^-) < 2.1 \times 10^{-10} @ 90\,\%\,CL$$





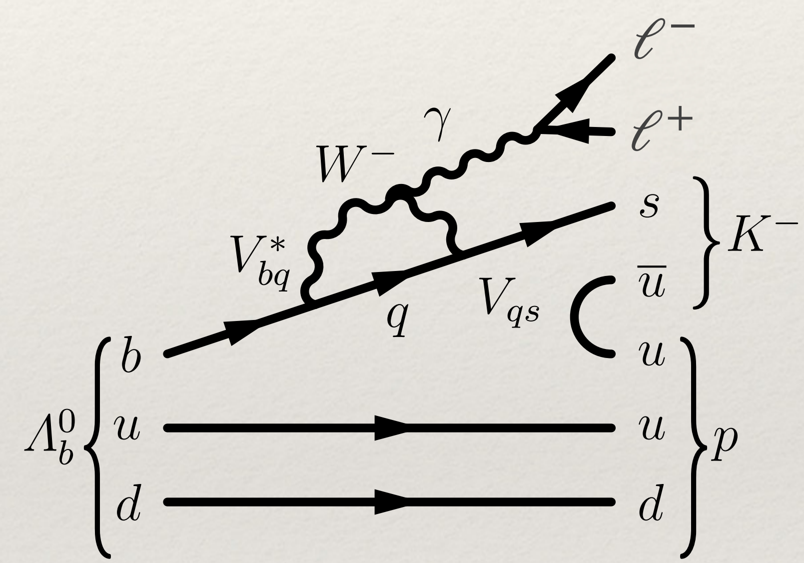
Tests of lepton-flavour universality

in $b \to s\ell^+\ell^-$ transitions

Lepton Flavour Universality

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

- Hints of non-universality seen with Run 1 LHCb data in $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}\ell^+\ell^-$ decays
  - 2019: updated LFU test with $B^+ \to K^+\ell^+\ell^-$ — PRL 122 (2019) 191801
    - LHCb data from 2011-16; $R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$: consistent with SM at 2.5σ
- LFU not probed in baryonic $b \to s\ell^+\ell^-$ transitions
  - Rare baryonic decays are sensitive to different spin-structure of BSM effects
  - The most abundant b-baryon: Λ_b^0



First test of LFU with $\Lambda_b^0 \to pK^-\ell^+\ell^-$ decays:

- Measure the double ratio: allows to cancel final-state-dependent systematics

$$R_{pK}^{-1} = \frac{\mathcal{B}(\Lambda_b^0 \to pK^-e^+e^-)_{q^2=(0.1,6)}}{\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-)_{q^2=(0.1,6)}} \times \frac{\mathcal{B}(\Lambda_b^0 \to pK^-J/\psi(\mu^+\mu^-))}{\mathcal{B}(\Lambda_b^0 \to pK^-J/\psi(e^+e^-))}$$

$q^2 \equiv m^2(\ell^+\ell^-)$

$r_{J/\psi}^{-1}$: equals to 1 → stringent test of efficiencies

Dataset: Run 1, 2016 (4.7 fb^{-1})

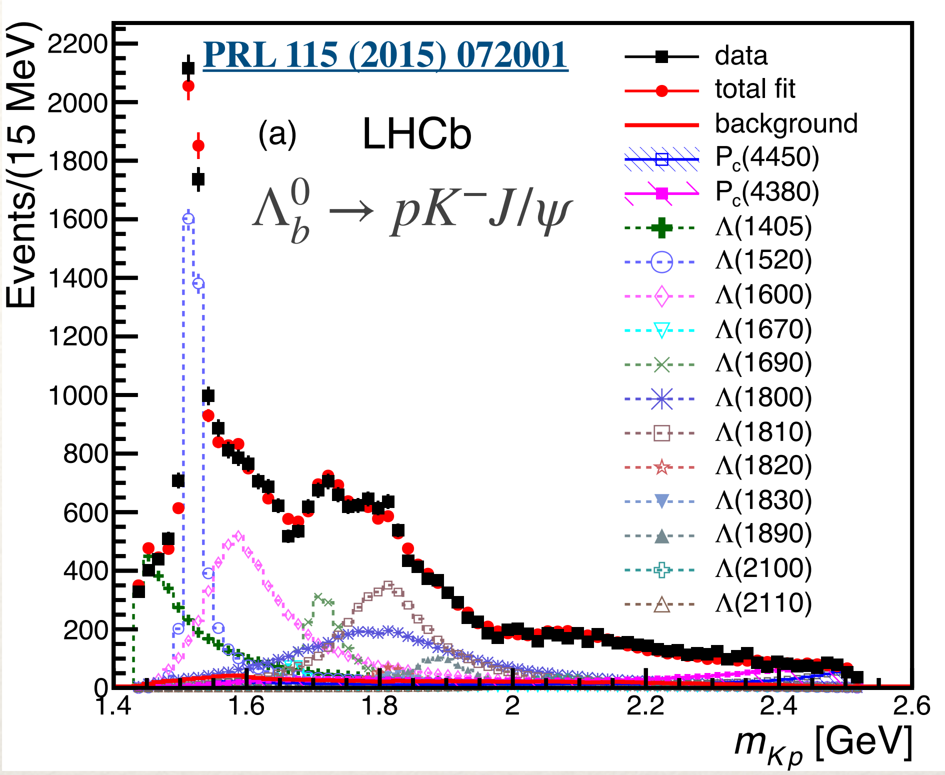
smaller electron yields are in the numerator: more symmetric behaviour of the likelihood.

Inverted w.r.t previous measurements!

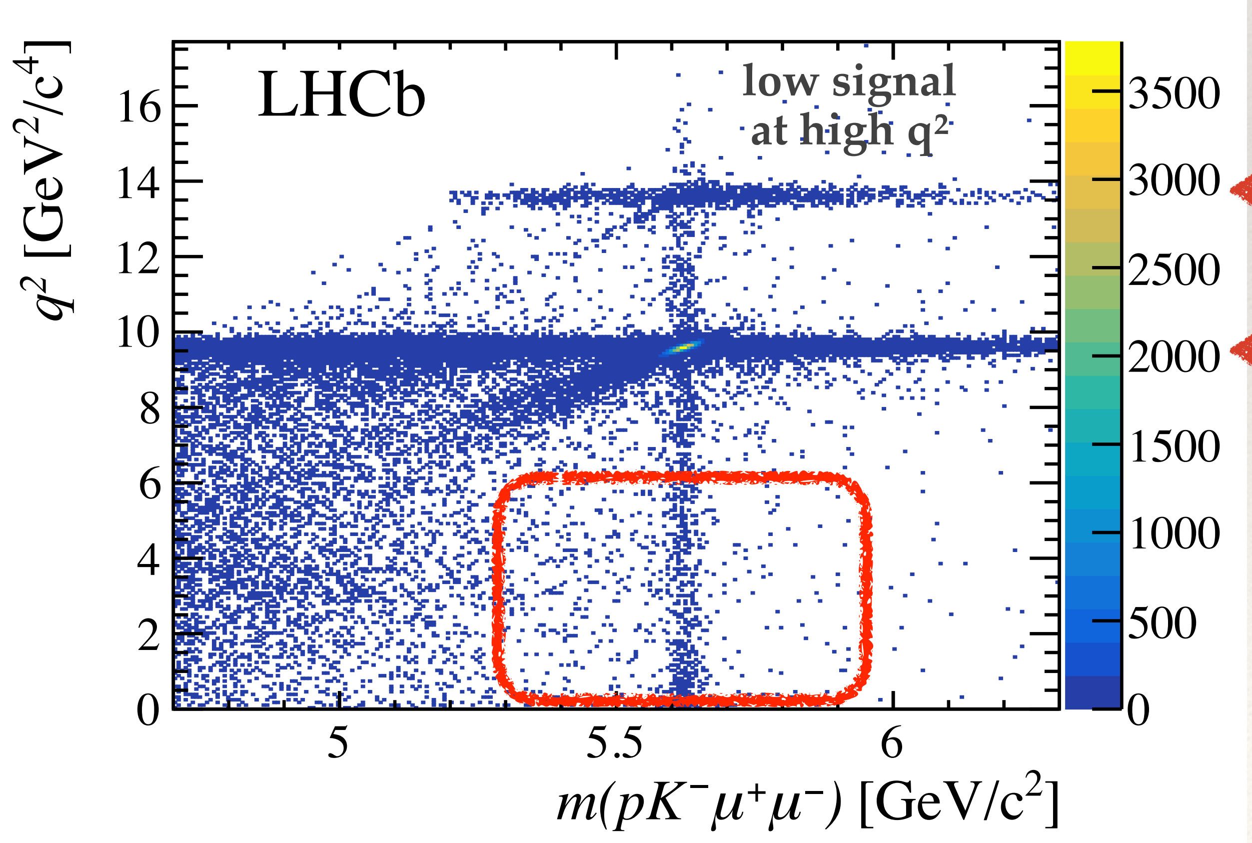
$pK^-\ell^+\ell^-$ travel map

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

- **Resonant** contributions from **charmonium** states
- For LFU test, use the region $0.1 < q^2 < 6$ GeV²:
  - far enough from charmonium and the dimuon threshold
  - get best use of our available dataset
- pK^- system: multiple overlapping Λ^* resonances of different J^P
  - Use range $m(pK^-) < 2.6$ GeV



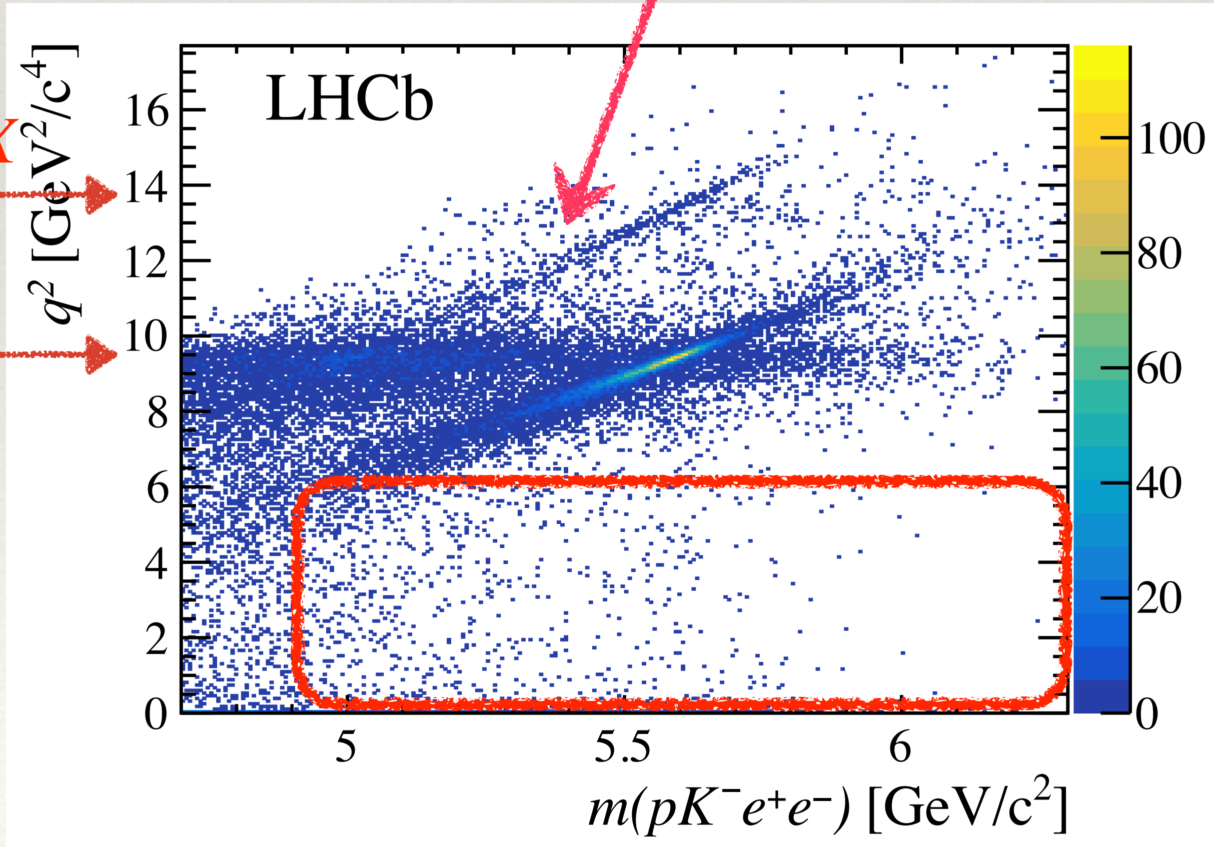
bremsstrahlung tails



$\psi(2S) + X$

$J/\psi + X$

signal window

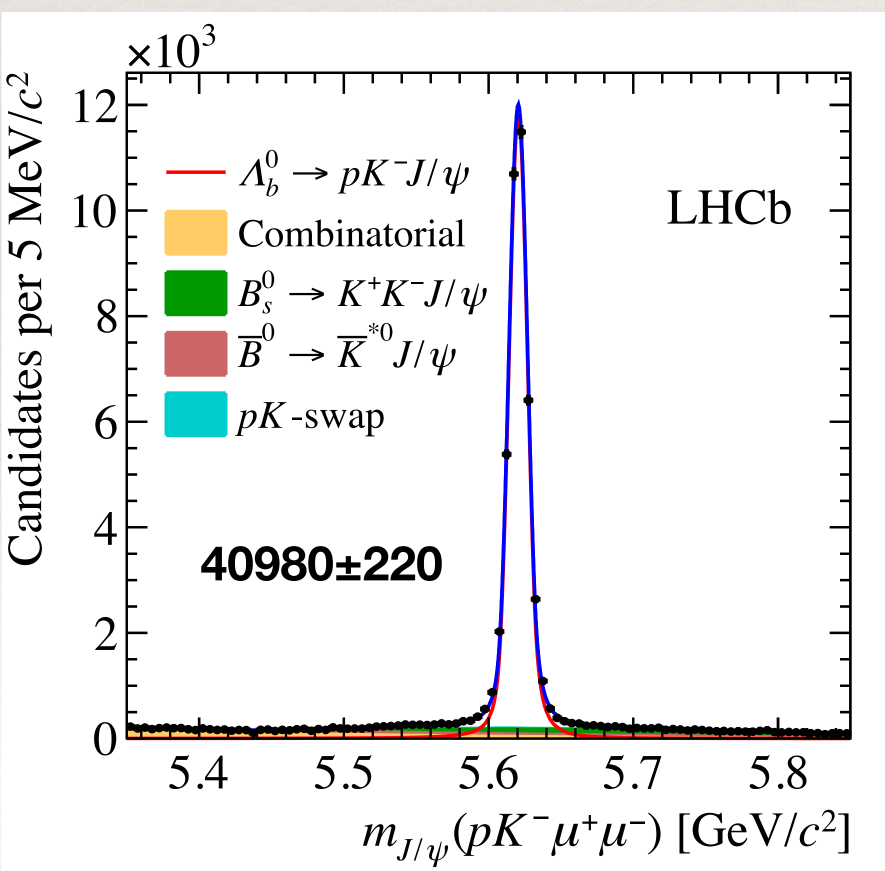


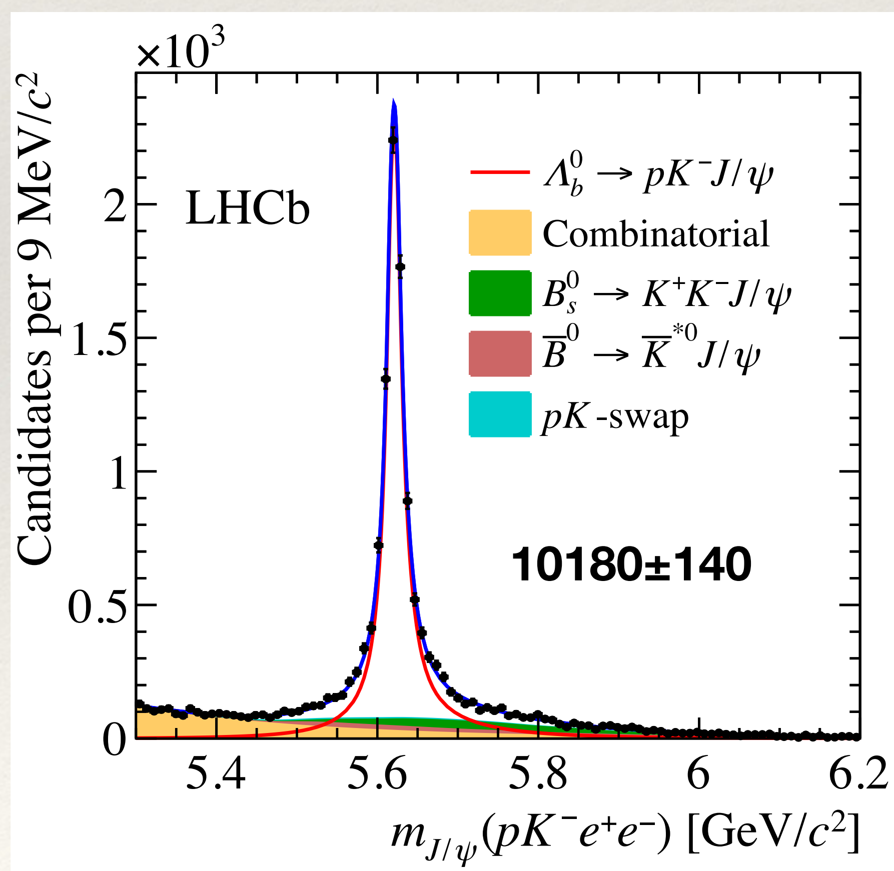
Cross-checks

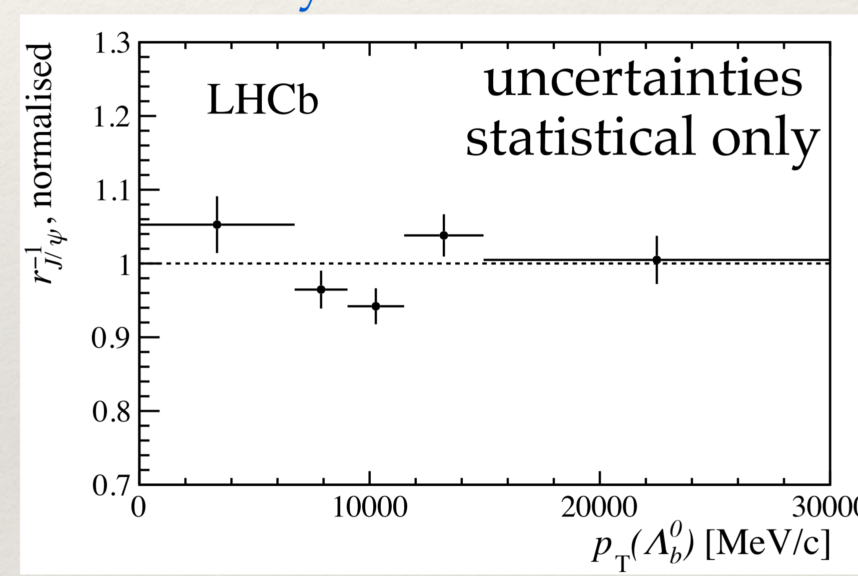
LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

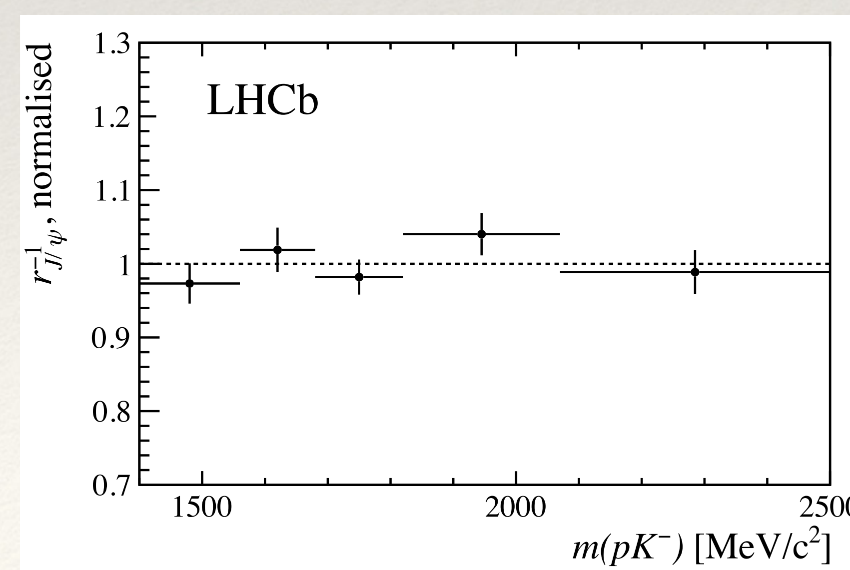
- Two *exclusive* trigger categories for the electron mode: TIS and electron
  - Very different calibration → agreement of the two is a stringent cross-check

- **Calibration of simulation** using $\Lambda_b^0 \to pK^- J/\psi(\ell^+\ell^-)$ data
  - Validated with the single ratio: $r_{J/\psi}^{-1} = 0.96 \pm 0.05$ consistent with unity
  - Stable in relevant variables, as expected





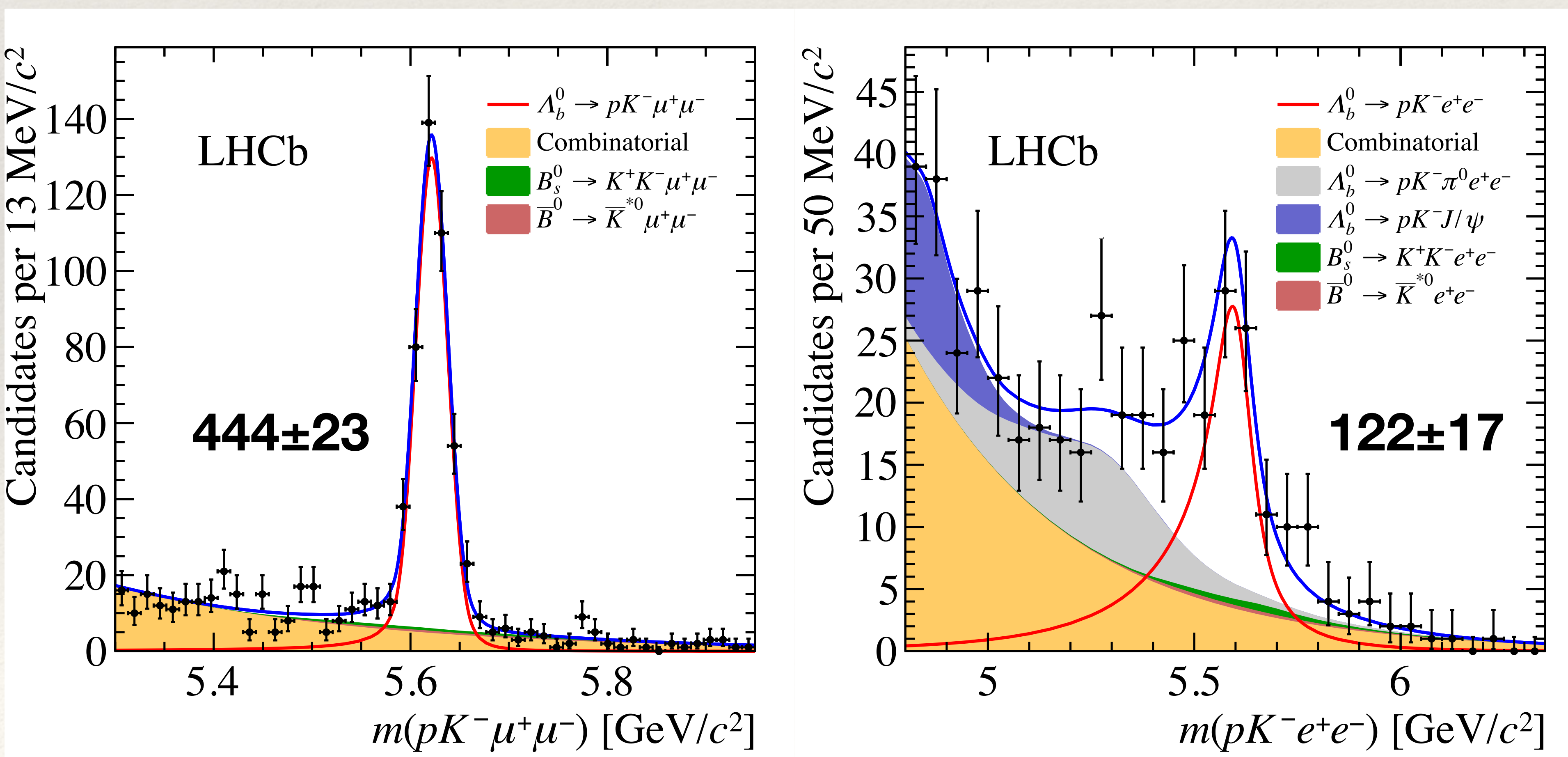




$\Lambda_b^0 \to pK^-\ell^+\ell^-$ mass fits

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

- Dominant backgrounds:
  - Random track combinations: suppressed by the MVA
  - Hadron **misidentifications**, such as $B_s^0 \to K^+_{\to p} K^- \ell^+ \ell^-$: suppressed by PID and selection, remaining contribution included in the mass fit
  - **Partially reconstructed** backgrounds: employed momentum balance in the decay



First observation of $\Lambda_b^0 \to pK^-e^+e^-$: significance > 7σ

main systematics: partially-reco shape in the fit

Results

- Test of LFU in $0.1 < q^2 < 6$ GeV², $m(pK) < 2600$ MeV:

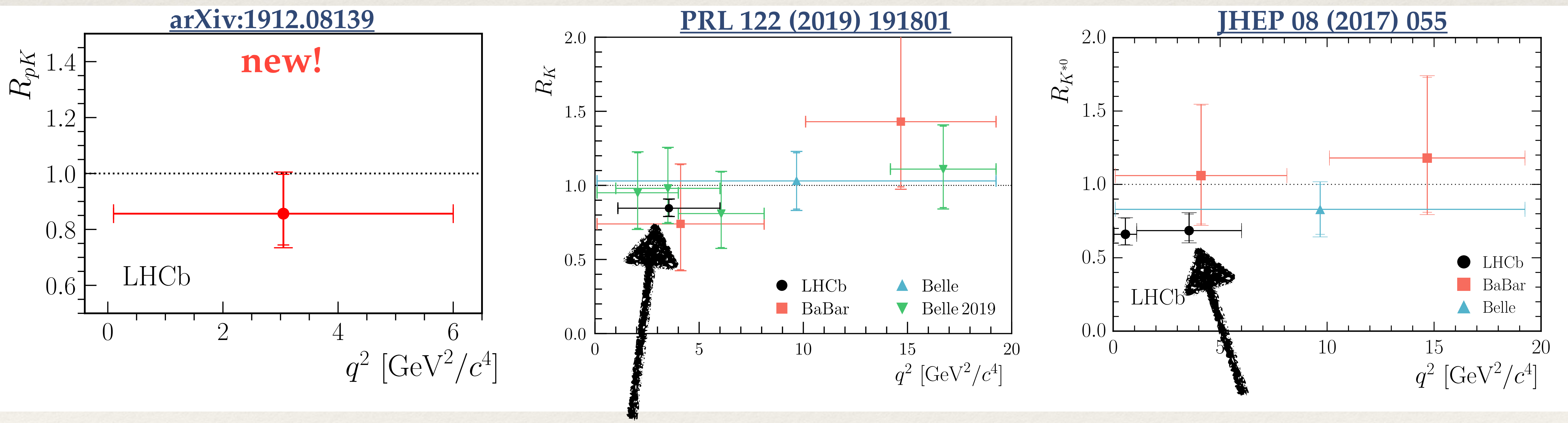
  $R_{pK}^{-1} = 1.17^{+0.18}_{-0.16} \pm 0.07$

  agrees with unity at $\sim 1\sigma$ level

  First LFU test with b-baryons!

  result statistically-dominated

- Invert the result, back to usual convention: $R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05$
  - points to the same direction as $R_{K^{(*)}}$ by LHCb



$R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05$	$R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$	$R_{K*} = 0.69^{+0.11}_{-0.07} \pm 0.05$
$0.1 < q^2 < 6$ GeV²	$1.1 < q^2 < 6$ GeV²	$1.1 < q^2 < 6$ GeV²

Other decays, suppressed or forbidden in the SM

Why LFV?

LHCb-PAPER-2019-043
arXiv:2003.04352
submitted to JHEP

- Lepton flavour is not protected by any fundamental symmetry in the SM
  - not conserved in neutrino oscillations
- Many models explaining the LFU violation, naturally predict the violation of lepton-flavour number: $h \to X\ell^+\ell'^-, \ell \neq \ell'$
  - **SM:** through neutrino oscillations, **decay rate negligibly small**
  - **BSM:** rate can be **enhanced** to the level reachable at LHCb

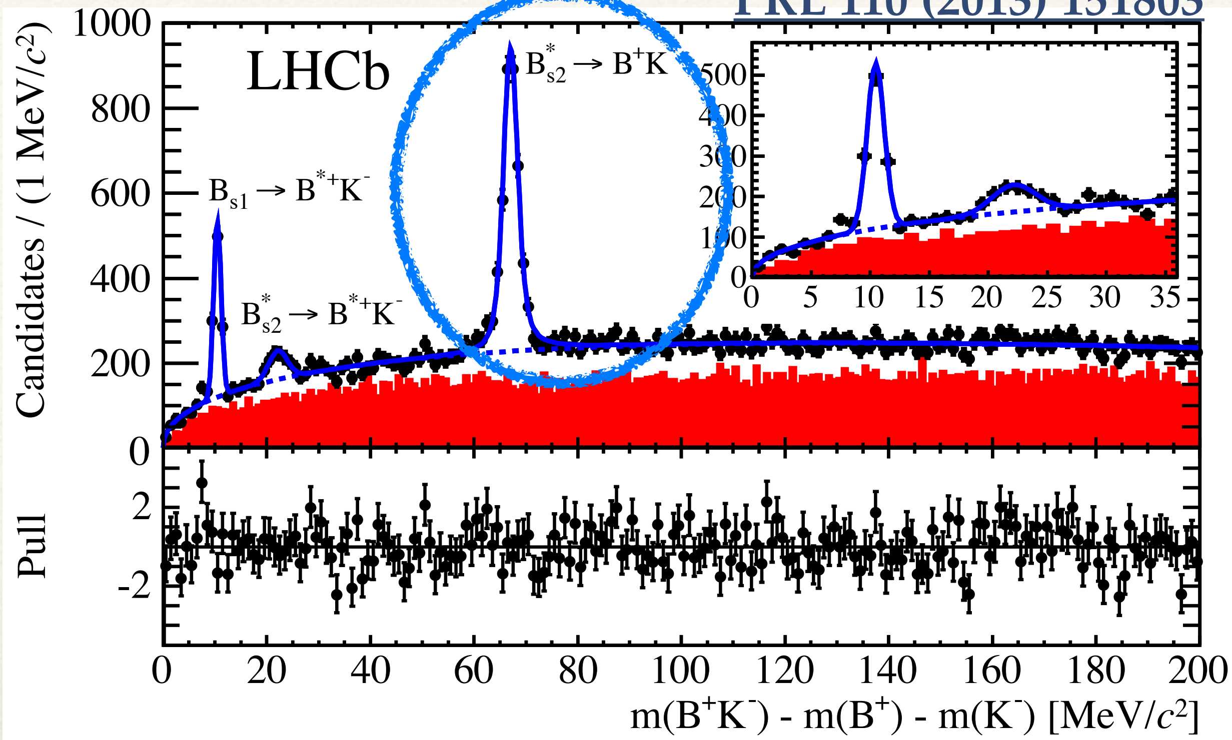
Dataset:
Run1, Run2
(9 fb^{-1})

- First search for $B^+ \to K^+\mu^-\tau^+$ at LHCb
  - BaBar: $\mathscr{B}(B^+ \to K^+\mu^-\tau^+) < 2.8 \times 10^{-5}$ @ 90 % CL [PRD 86, 012004]
  - $B^+ \to K^+\mu^-\tau^+$ has **less background** from semileptonic $B \to \overline{D}\mu^+\nu_\mu X$ decays, than $B^+ \to K^+\mu^+\tau^-$
- Experimental challenge: partially-reconstructed tau lepton decays with missing neutrinos
  - we developed dedicated techniques for partial reconstruction

From spectroscopy to rare decays

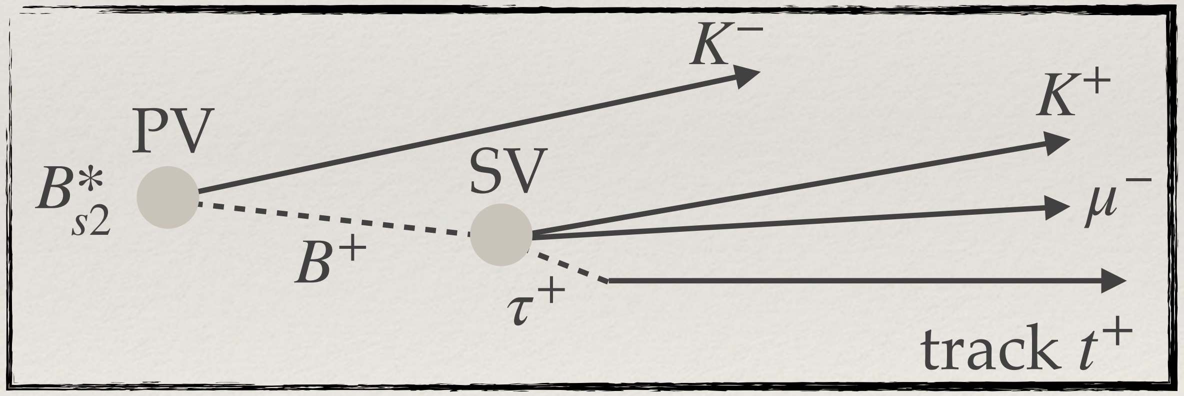
[LHCb-PAPER-2019-043](#)
[arXiv:2003.04352](#)
submitted to JHEP
[PRL 110 (2013) 151803](#)

- Narrow excited B^*_{s2} state decaying to B^+K^- observed at Tevatron in 2008



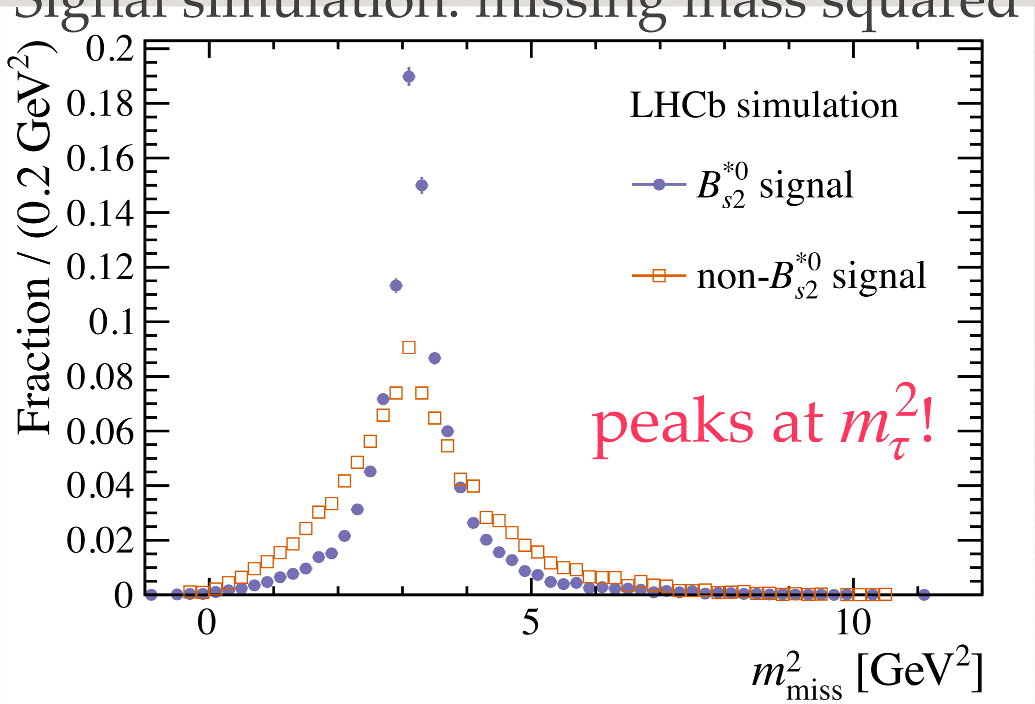
> **Idea: use B^*_{s2} to tag B^+ mesons**
> - use momentum of the kaon;
> - mass constraints for B^*_{s2} and B^+;
> - and their vertex constraints.
>
> Energy of B^+ can be determined up to a quadratic ambiguity

Inclusive selection of τ^+ decay to one track + X



- We can reconstruct the missing mass:

Signal simulation: missing mass squared



No peaking backgrounds

with $m^2_{miss} \sim m^2_\tau$!

Search for $B^+ \to K^+\mu^-\tau^+$: results

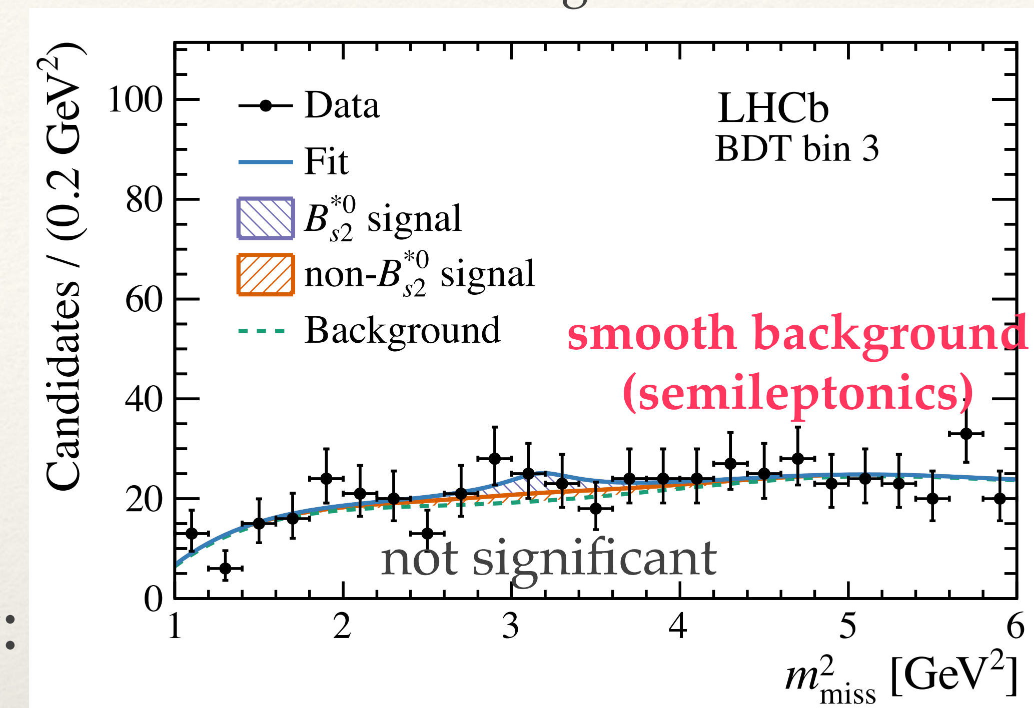
LHCb-PAPER-2019-043
arXiv:2003.04352
submitted to JHEP

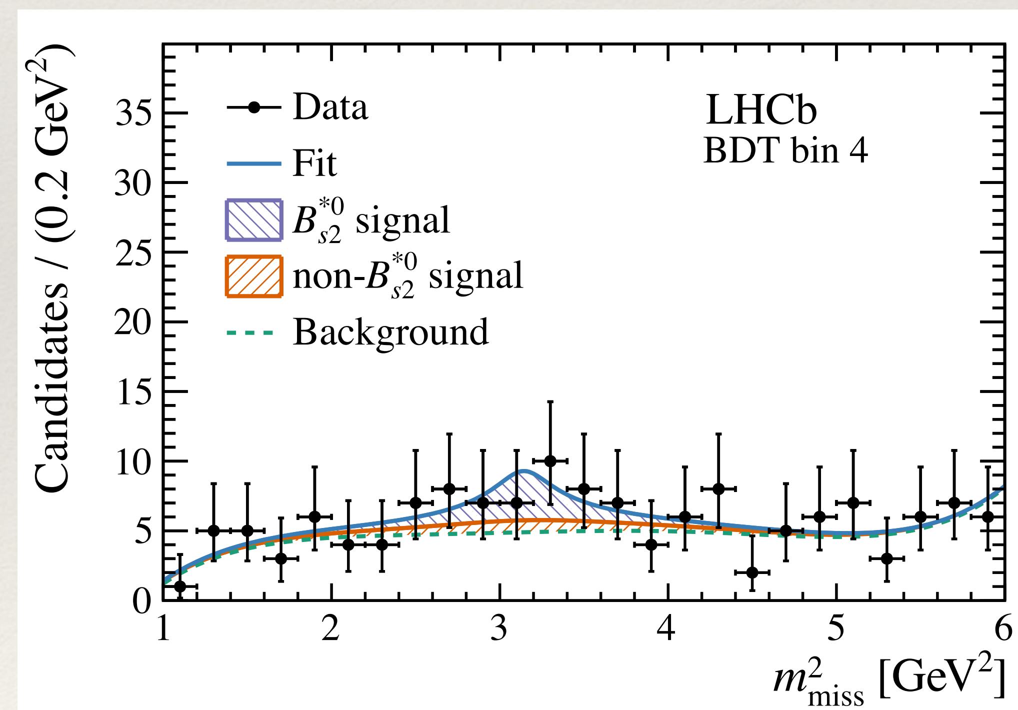
- Multivariate selection
  - Fit to data in 4 bins of MVA output
- Require $m(K^+\mu^-t^+)_{t\to\mu} < 4.8$ GeV to remove $B^+ \to K^+c\bar{c}(\mu^+\mu^-)$
- $B^+ \to K^+J/\psi(\mu^+\mu^-)$ used as **normalisation channel**
- **No significant signal found** , set an upper limit:

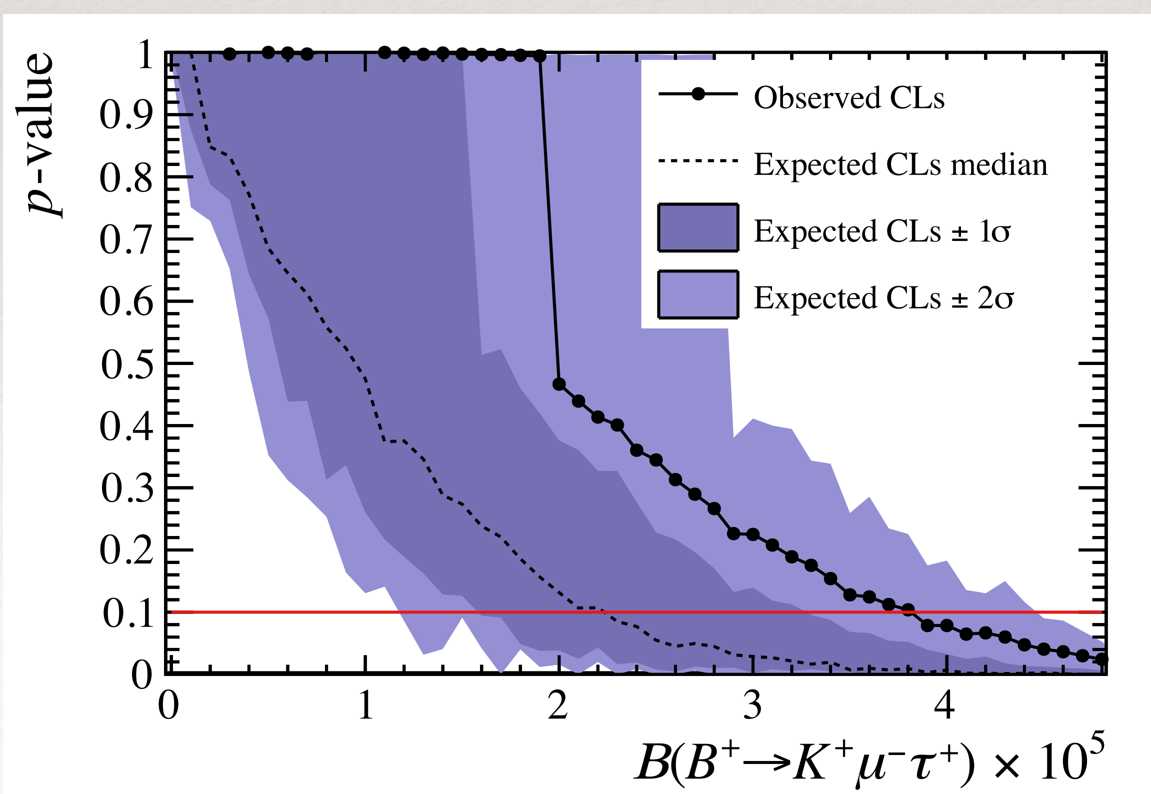
$$\mathscr{B}(B^+ \to K^+\mu^-\tau^+) < 3.9 \times 10^{-5} @ 90\,\%\,CL$$

  - slightly above the BaBar limit.

two bins of highest MVA score







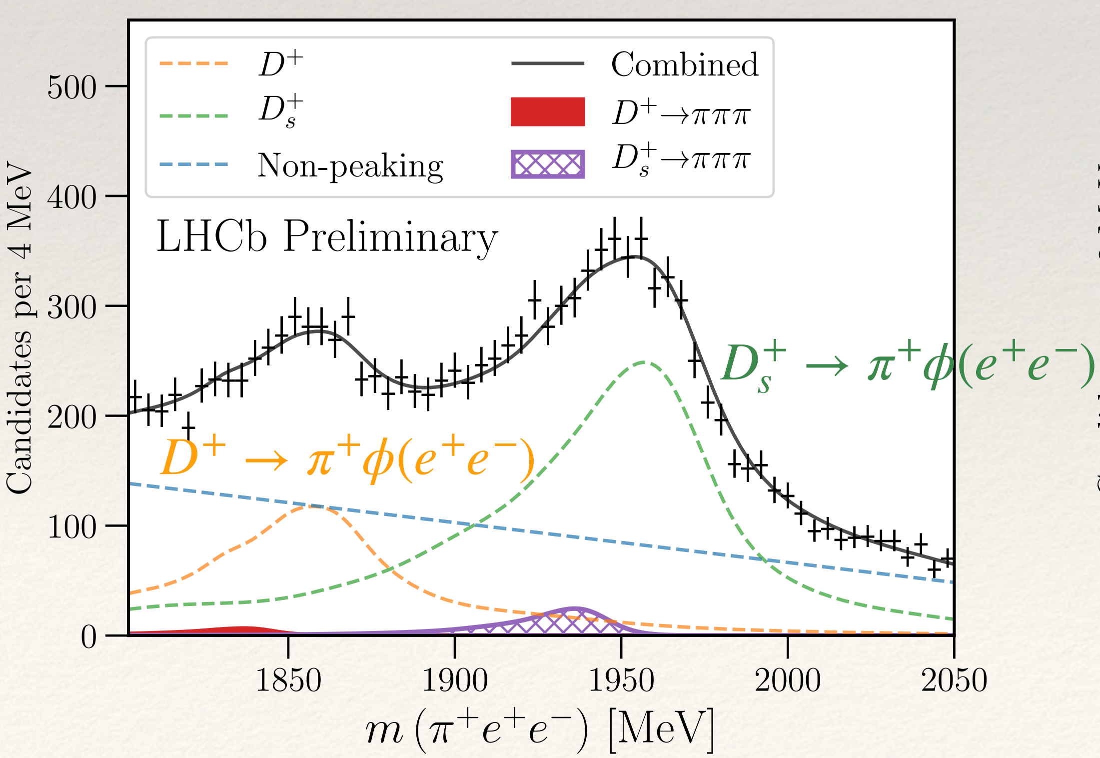
Main result: new technique for decays with taus!

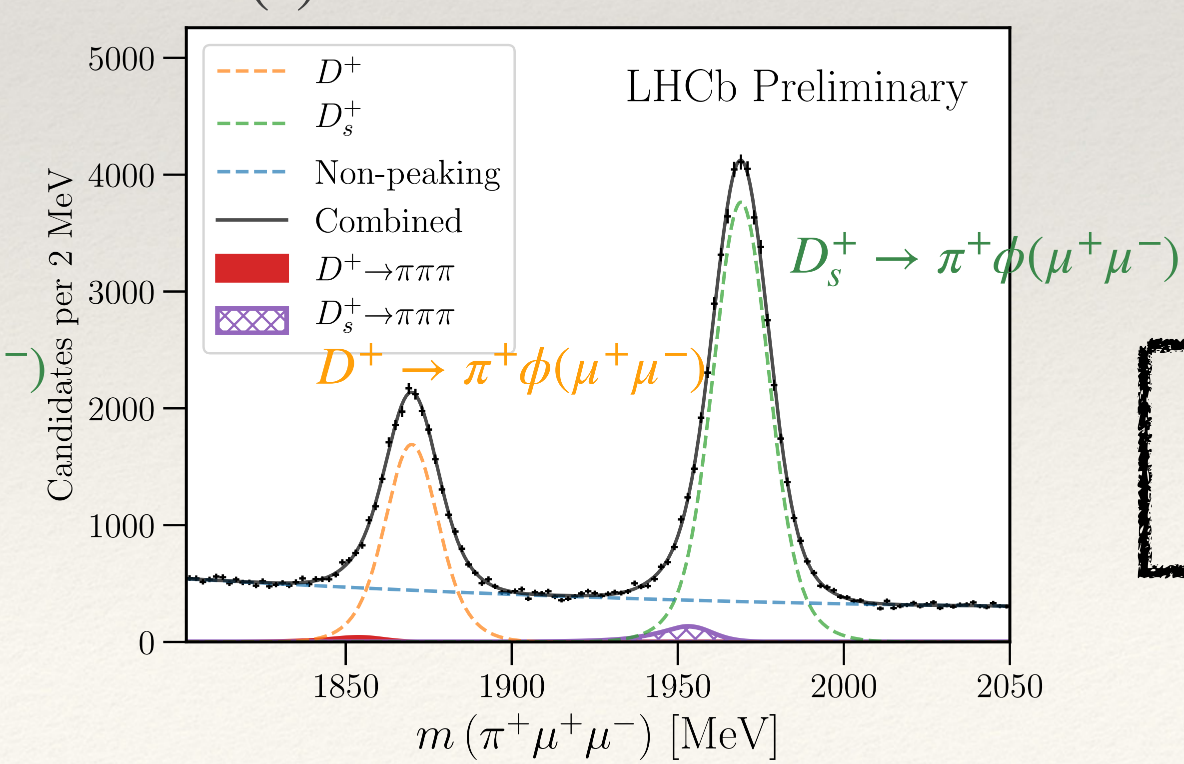
Search for 25 $D^+_{(s)} \to h\ell\ell$ modes

NEW!
LHCb-PAPER-2020-007
(in preparation)

- **Four** rare charm decays $D^+ \to \pi^+\ell^+\ell^-$ and $D^+_s \to K^+\ell^+\ell^-$: $(\ell = e, \mu)$
  - $c \to u\ell^+\ell^-$ and weak annihilation diagrams
  - dominated by light resonances $(\eta, \rho, \omega, \phi \to \ell^+\ell^-)$
    - excluded the region $525 < m(\ell^+\ell^-) < 1250$ MeV
- **Four** weak-annihilation decays $D^+ \to K^+\ell^+\ell^-$ and $D^+_s \to \pi^+\ell^+\ell^-$
- **Eight** $D^+_{(s)} \to h^+\ell^+\ell'^-$ **LFV** modes $(h = \pi, K)$
- **Nine** $D^+_{(s)} \to h^-\ell^+\ell^+$ and $D^+_{(s)} \to h^-\ell^+\ell'^+$ **LNV** modes

- Normalised and calibrated with $D^+_{(s)} \to \pi^+\phi(\ell^+\ell^-)$





Dataset:
2016
(1.7 fb^{-1})

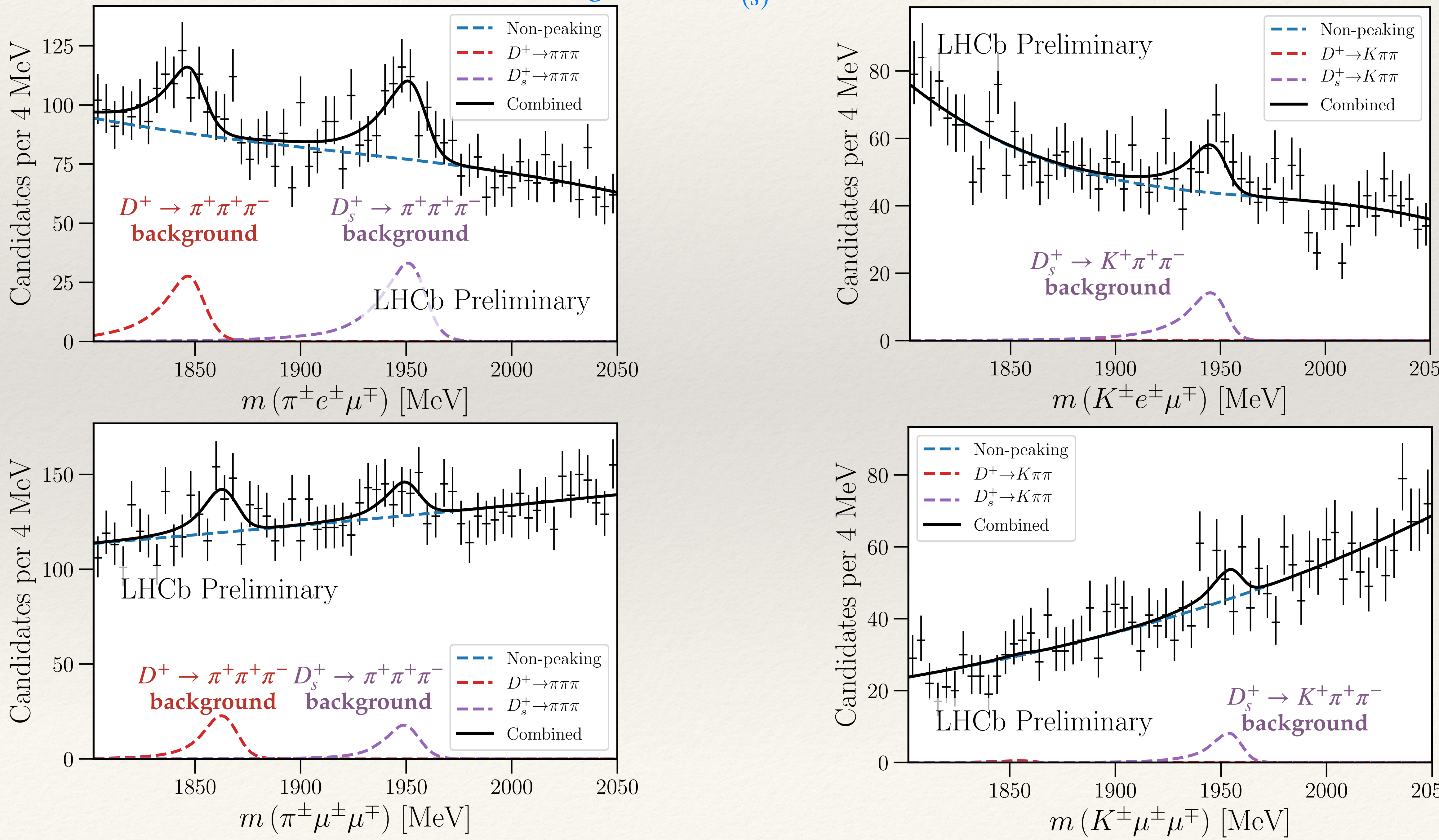
Mass distributions

NEW!
LHCb-PAPER-2020-007
(in preparation)

- PID selection suppresses $D^+_{(s)} \to 3h$
  - In some cases, misID background is significant
- Data in all channels well described by **background-only shape**

other fits shown in backup slides

misidentification backgrounds $D^+_{(s)} \to 3h$ are under control



Limits

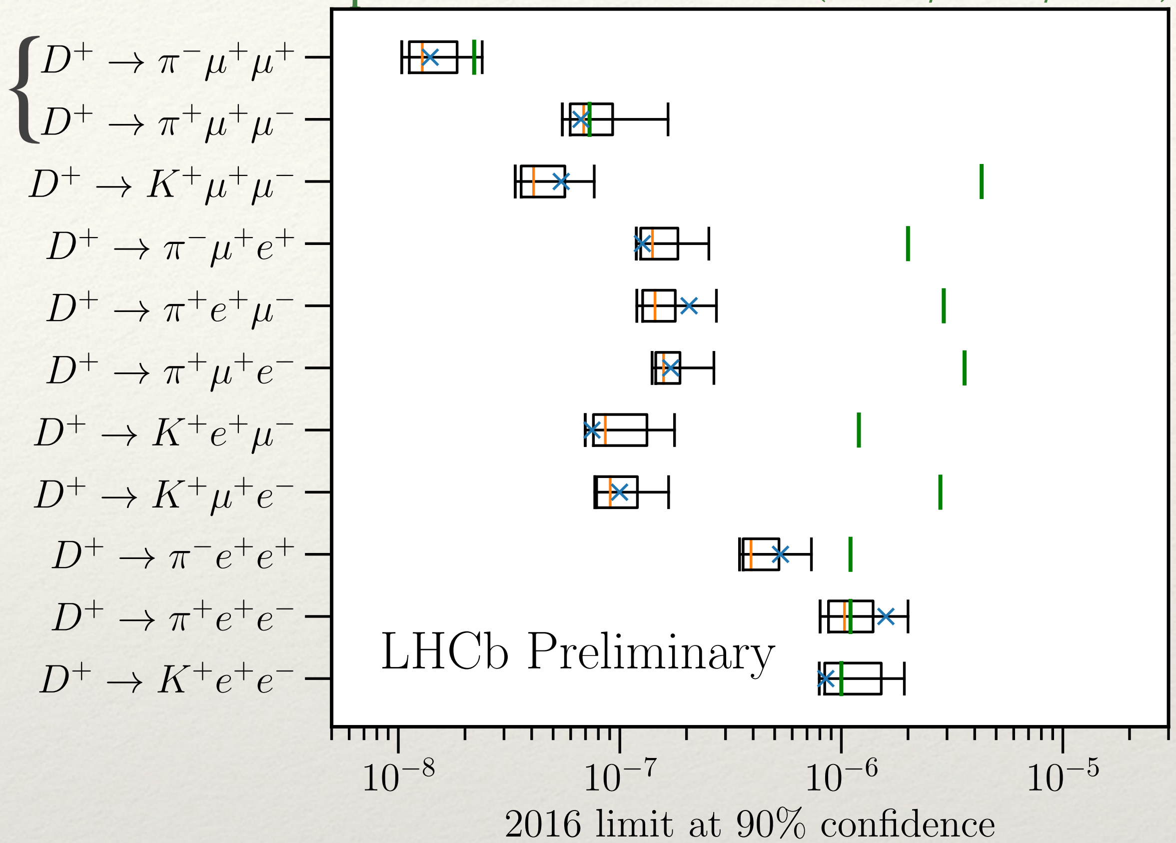
NEW!
LHCb-PAPER-2020-007
(in preparation)

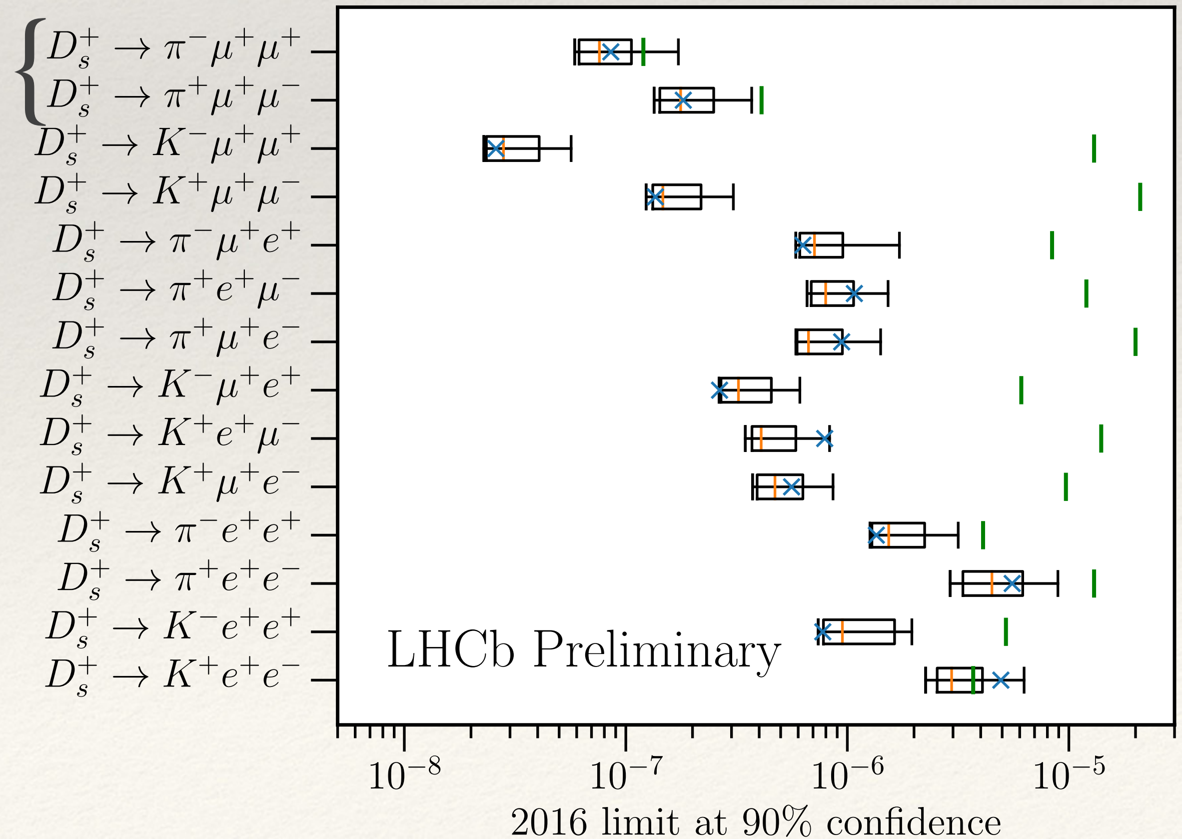
- 23 world's best limits

Decay LHCb preliminary	Branching fraction upper limit $[10^{-9}]$ D^+ 90% CL	D^+ 95% CL	D_s^+ 90% CL	D_s^+ 95% CL	Improvement D^+	Improvement D_s^+
$D^+_{(s)} \to \pi^+\mu^+\mu^-$	67	74	180	210	1.1	2.3
$D^+_{(s)} \to \pi^-\mu^+\mu^+$	14	16	86	96	1.6	1.4
$D^+_{(s)} \to K^+\mu^+\mu^-$	54	61	140	160	79.0	150.0
$D^+_{(s)} \to K^-\mu^+\mu^+$	-	-	26	30	-	500.0
$D^+_{(s)} \to \pi^+e^+\mu^-$	210	230	1100	1200	14.0	11.0
$D^+_{(s)} \to \pi^+\mu^+e^-$	220	220	940	1100	16.0	21.0
$D^+_{(s)} \to \pi^-\mu^+e^+$	130	150	630	710	16.0	13.0
$D^+_{(s)} \to K^+e^+\mu^-$	75	83	790	880	16.0	18.0
$D^+_{(s)} \to K^+\mu^+e^-$	100	110	560	640	28.0	17.0
$D^+_{(s)} \to K^-\mu^+e^+$	-	-	260	320	-	23.0
$D^+_{(s)} \to \pi^+e^+e^-$	1600	1800	5500	6400	0.7	2.3
$D^+_{(s)} \to \pi^-e^+e^+$	530	600	1400	1600	2.1	3.0
$D^+_{(s)} \to K^+e^+e^-$	850	1000	4900	5500	1.2	0.8
$D^+_{(s)} \to K^-e^+e^+$	-	-	770	840	-	6.7

| expected median, with $\pm 1\sigma$, $\pm 2\sigma$ intervals
x observed limit
| previous world's best limit (BaBar / CLEO/ LHCb)

Previous limit is LHCb Run 1
Phys. Lett. B724 (2013) 203





2017-18 dataset yet to be analysed.

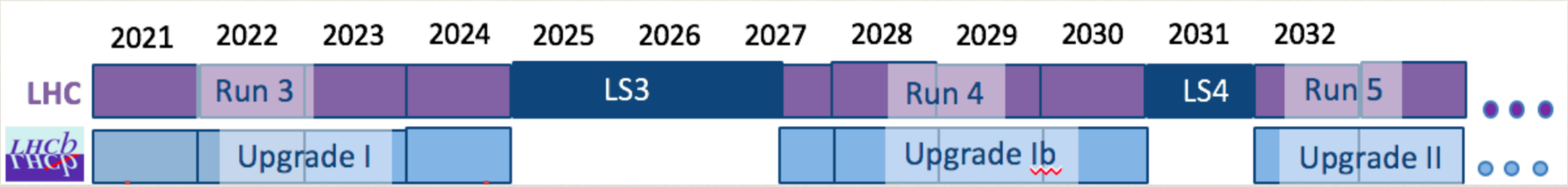
Summary

- LHCb is actively analysing its rich dataset of rare **strange**, **charm** and **beauty** decays
- Covered today new LHCb results which came out in the last few months:
  - searches for $B^0_{(s)} \to e^+e^-$, $B^+ \to K^+\tau^-\mu^+$, $K_S \to \mu^+\mu^-$ and 25 $D^+_{(s)} \to h\ell\ell$ modes;
  - first test of lepton-flavour universality in rare baryonic decays.
- We analyse new channels and update old results
  - several first observations, or first limits
  - most of the results still statistically dominated
- Sensitivity to several channels enters the region interesting to probe BSM models
- We find new interplays between the rare decays and hadron spectroscopy
- **Many results with the full Run 1 and Run 2 dataset are coming**

Prospects

- We are upgrading the LHCb: it will be essentially a new detector
- Main goals of the Upgrade:
  - collect **larger datasets**, up to 50 fb^{-1} by 2030
  - remove the **bottlenecks** in our **trigger**
- Upgrade II is in preparation

arXiv:1808.08865



- Expect a healthy competition with Belle II, CMS and ATLAS
- Bright times ahead for the precision flavour physics!

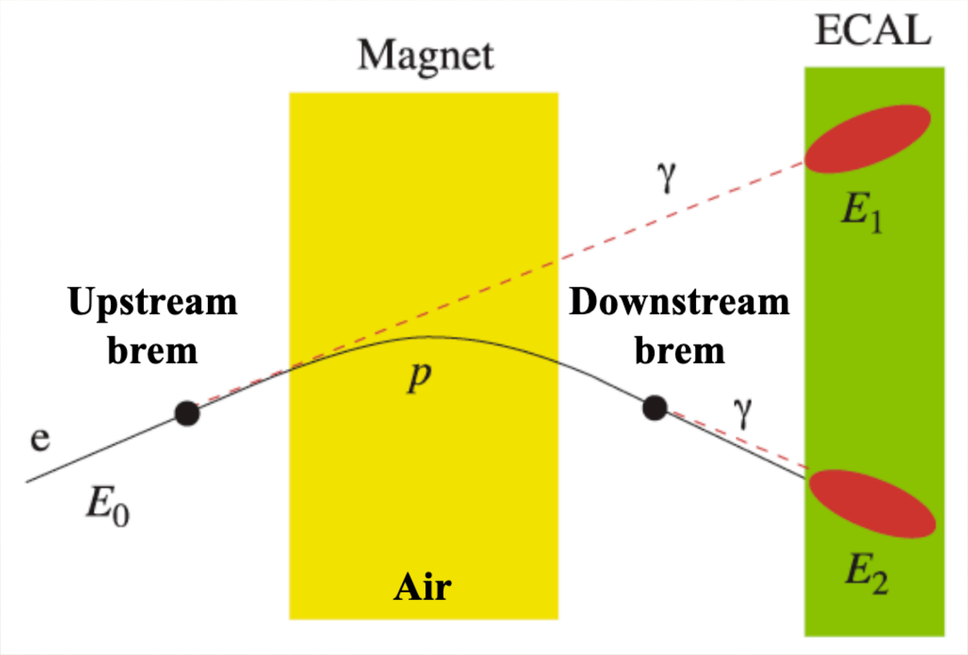
Thanks for your attention!

Stay along for the talk of Emmy Gabriel on discoveries of new hadrons!

Extras

Electrons in LHCb

- **Electrons** emit a large amount of **bremsstrahlung** in interactions with the detector material



- **If a photon is emitter *after the magnet*:**
  - momentum of the electron measured correctly
  - energies of the photon and electron are deposited in the same ECAL cell

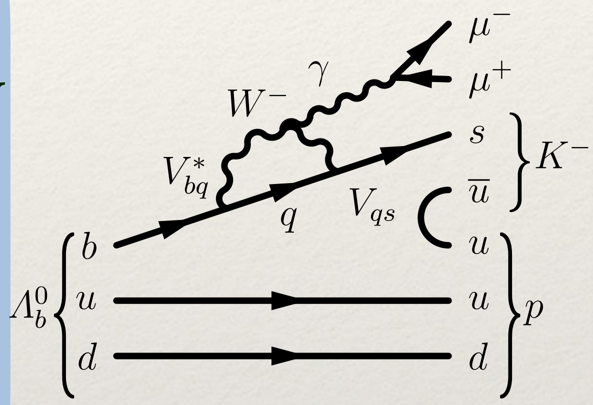
- **If a photon is emitted *before the magnet*:**
  - momentum is measured *after* bremsstrahlung
  - photon ends up in a *different* ECAL cell
    - dedicated procedure to search for these photons and correct the electron momenta
    - Not a perfect correction, **affects the resolution**

LFU with baryons

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

- Production rate of Λ_b^0: $\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018$ at 13 TeV [PRD 100 (2019) 031102(R)]
  - plenty of Λ_b^0 decays recorded at LHCb

- Baryonic $b \to s\ell^+\ell^-$ decays observed by 2019:
  - $\Lambda_b \to \Lambda\mu^+\mu^-$: long-lived neutral Λ, small efficiency
  - $\Lambda_b \to pK\mu^+\mu^-$: **our choice for LFU test**
  - $\Lambda_b \to p\pi\mu^+\mu^-$: Cabibbo-suppressed
- No baryonic $b \to se^+e^-$ mode seen before



Dataset:
Run 1, 2016
(4.7 fb-1)

- First test of LFU with $\Lambda_b \to pK\ell^+\ell^-$ decays:

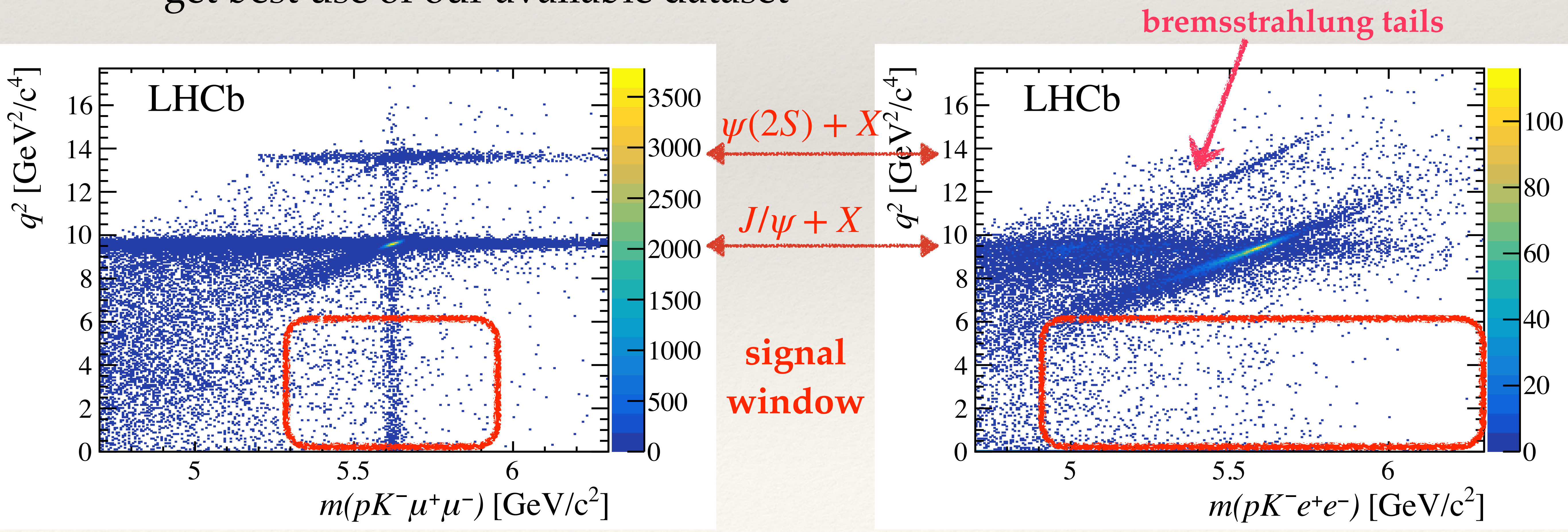
$$R_{pK}^{-1} = \frac{\mathcal{B}(\Lambda_b^0 \to pK^-e^+e^-)_{q^2=(0.1,6)}}{\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-)_{q^2=(0.1,6)}} \times \frac{\mathcal{B}(\Lambda_b^0 \to pK^-J/\psi(\mu^+\mu^-))}{\mathcal{B}(\Lambda_b^0 \to pK^-J/\psi(e^+e^-))}$$

  - smaller electron yields are in the numerator: more symmetric behavior of the likelihood. Inverted w.r.t previous measurements!

$pK^-\ell^+\ell^-$ travel map

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

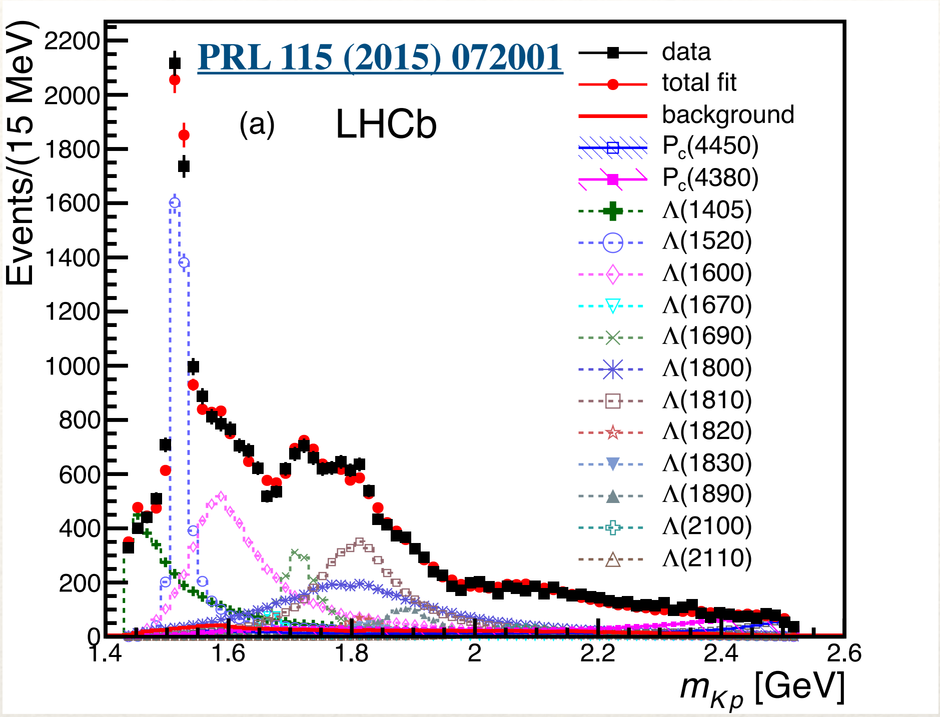
- Similarly to other b-hadron decays, there are **resonant** contributions from **charmonium** states
  - The $\Lambda_b^0 \to pK^-\psi(2S)(\ell^+\ell^-)$ contribution is much smaller than in other b-hadron decays, due to **closeness to the upper mass threshold**
  - Almost no signal in "high-q²" region above the $\psi(2S)$
- For LFU test, use the region $0.1 < q^2 < 6$ GeV²:
  - far enough from charmonium and the dimuon threshold
  - get best use of our available dataset

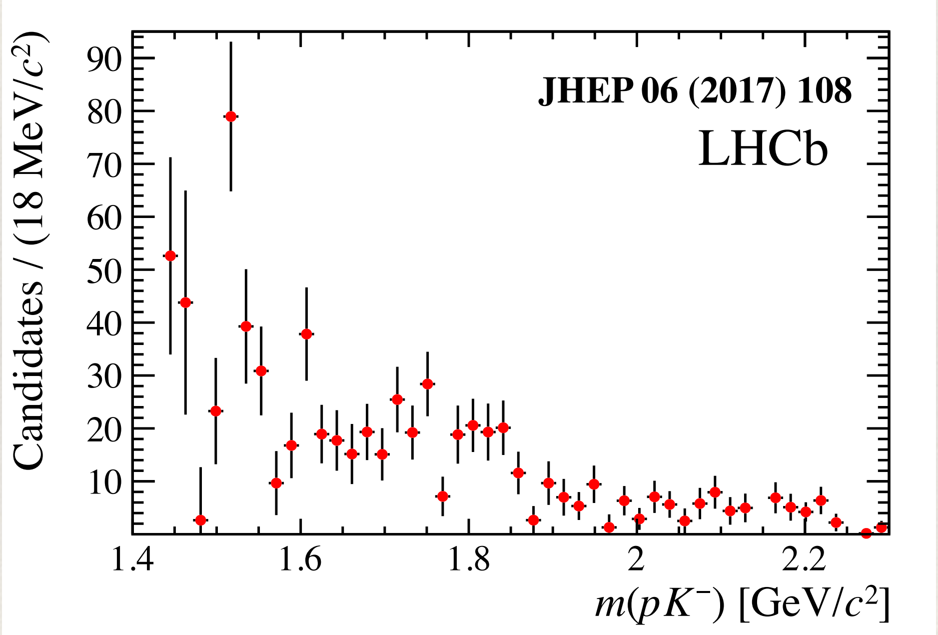


$m(pK^-)$ travel map

LHCb-PAPER-2019-040
arXiv:1912.08139
accepted by JHEP

- $\Lambda_b^0 \to pK^- J/\psi$: multiple overlapping $\Lambda^* \to pK^-$ resonances of different J^P
  - and some pentaquarks in $J/\psi p$!
- $\Lambda_b^0 \to pK^- \mu^+ \mu^-$: similar, but not necessarily the same resonant content
  - difficult to separate one single resonance
  - this complicates theoretical interpretation of our result
- Large phase-space, but almost no signal at high $m(pK^-)$: this analysis restricted to $m(pK^-) < 2.6$ GeV





Search for $B_{(s)} \to e^+e^-$

LHCb-PAPER-2020-001
arXiv:2003.03999
accepted by PRL

- LHC experiments searched for $B^0_{(s)} \to \mu^+\mu^-$ and $B^0_{(s)} \to \tau^+\tau^-$, this is the first search for $B_{(s)} \to e^+e^-$ at LHC
  - Test of LFU w.r.t. $B^0_{(s)} \to \mu^+\mu^-$

Dataset:
2011-2016
(5 fb^{-1})

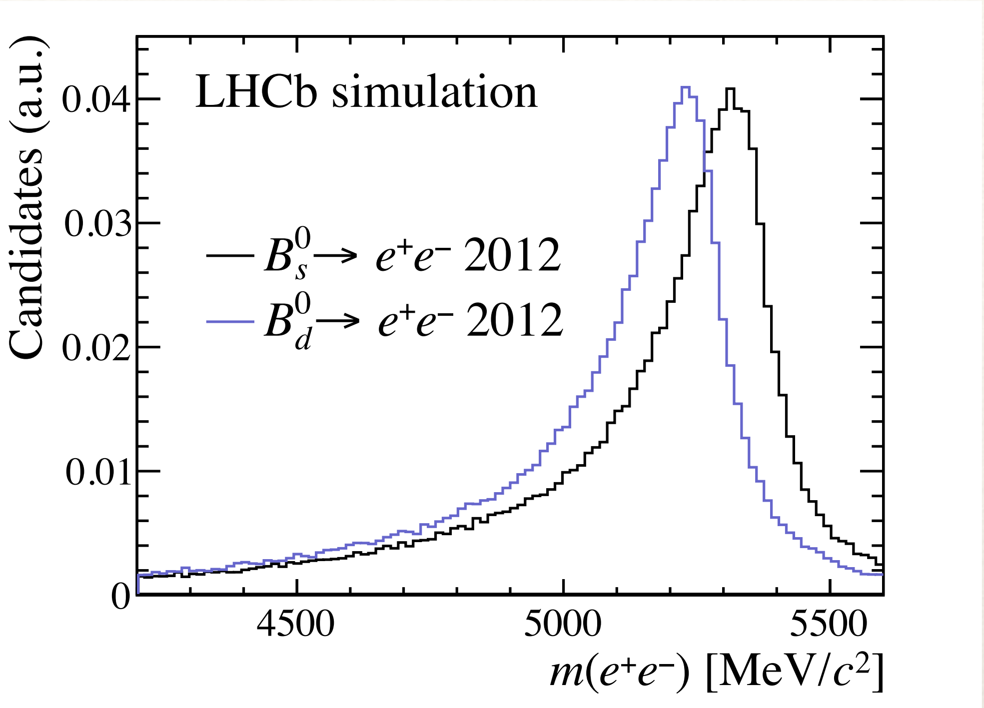
- $B^+ \to K^+ J/\psi(e^+e^-)$ taken as a normalisation channel
  - Cancellation of uncertainties due to electron reconstruction

- **Multivariate selection** against random track combinations
  - relies on the **kinematics**, **geometry** and **isolation** tools
- **Partially reconstructed** backgrounds can survive this selection, are included in the invariant-mass fit
  - their mass shapes are not peaking
  - misidentified $B^0 \to \pi^- e^+ \nu_e$ is the closest to the signal region
- **PID selection** applied to strongly suppress **misidentifications**
  - Special care for misidentified $B^0_{(s)} \to h^+h^-$: located in the signal region

Mass resolution

LHCb-PAPER-2020-001
arXiv:2003.03999
accepted by PRL

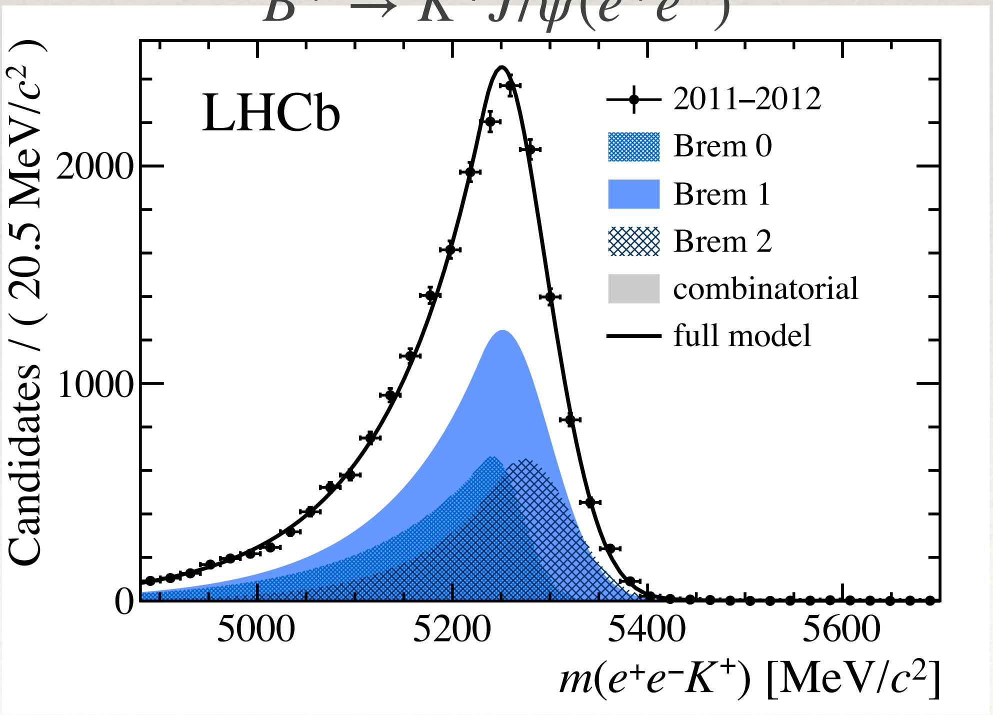
- Mass **resolution** is **degraded** by bremsstrahlung



- Makes it difficult to separate the B^0 and B_s^0 signals
  - Search for each mode separately, assuming absence of the other

- Mass resolution depends on the **number of recovered bremsstrahlung photons**
  - studied with $B^+ \to K^+J/\psi(e^+e^-)$ data:

$B^+ \to K^+J/\psi(e^+e^-)$

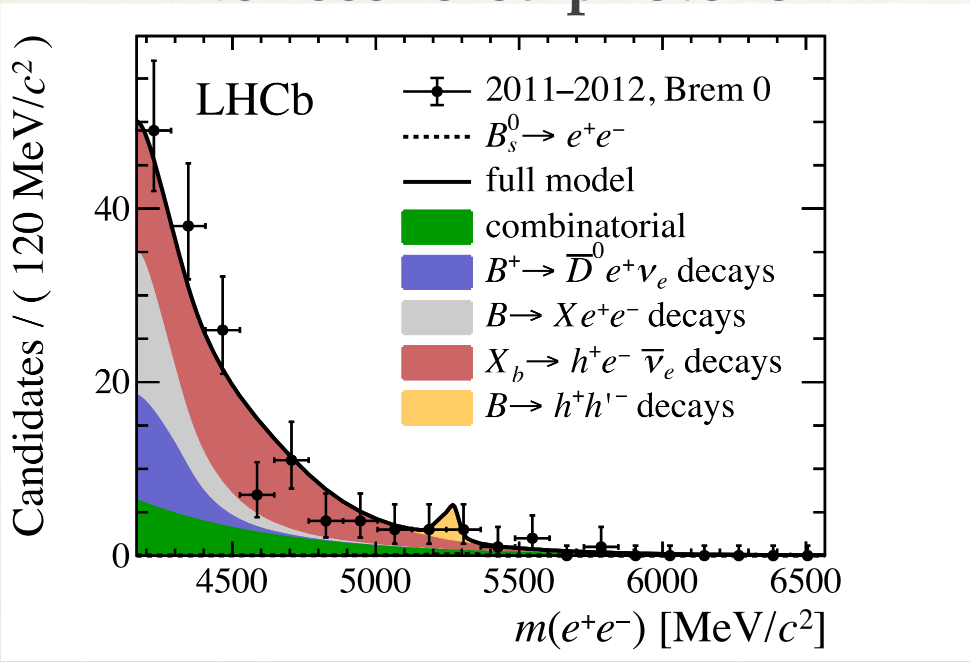


- **Analysis is performed in three categories of bremsstrahlung recovery separately**

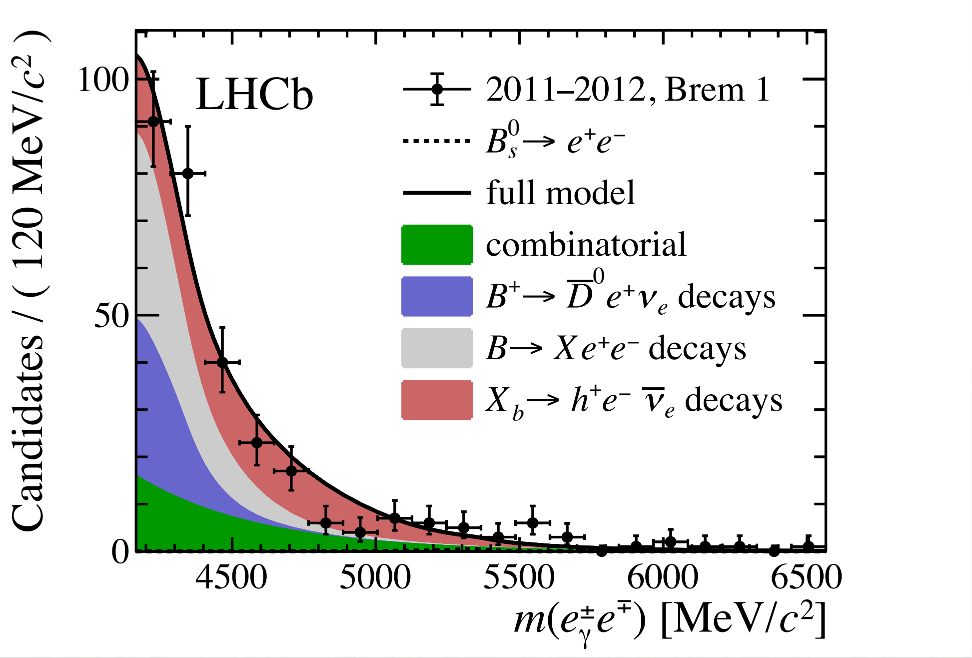
Bremsstrahlung and PID

- Bremsstrahlung recovery **improves** the **electron ID**
  - only electrons emit a significant amount of radiation
- **Different background composition between the three categories:**

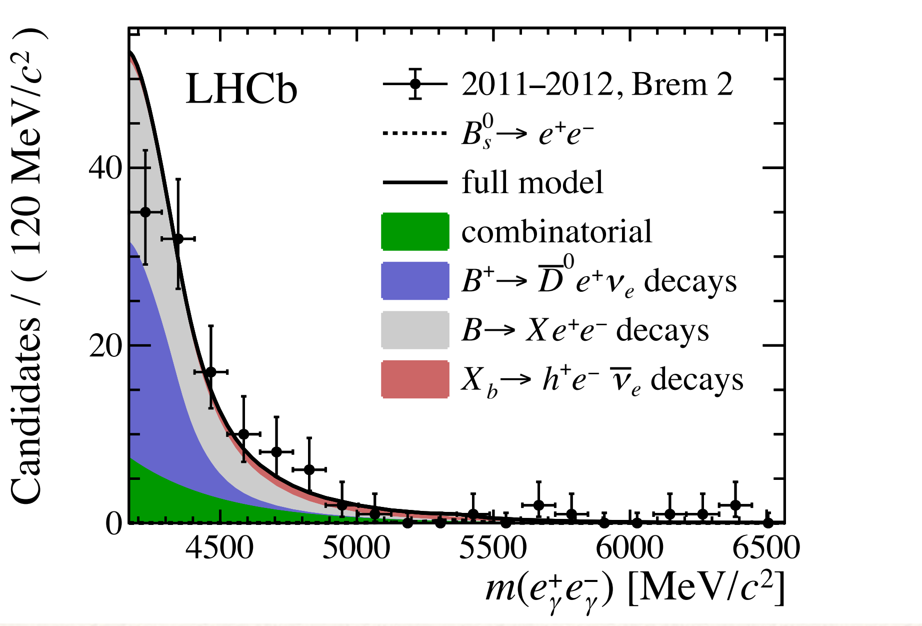
No recovered photons



Photon recovered for one electron



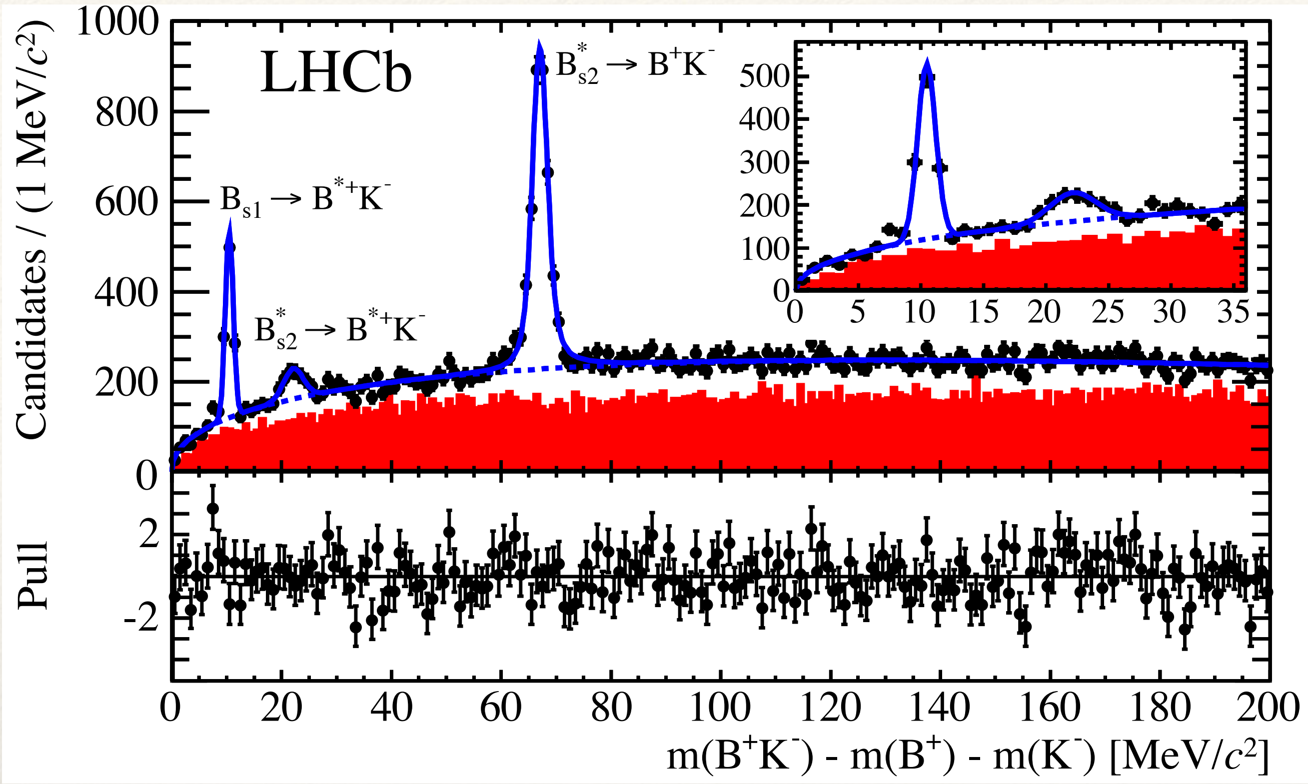
Photons recovered for both electrons



From hadron spectroscopy to rare decays

- Narrow excited B^*_{s2} state decaying to B^+K^- observed by CDF and D0
  - confirmed by LHCb in 2013
  - about 1% of B^+ mesons originate from decays of B^*_{s2}

Phys. Rev. Lett. 110 (2013) 151803



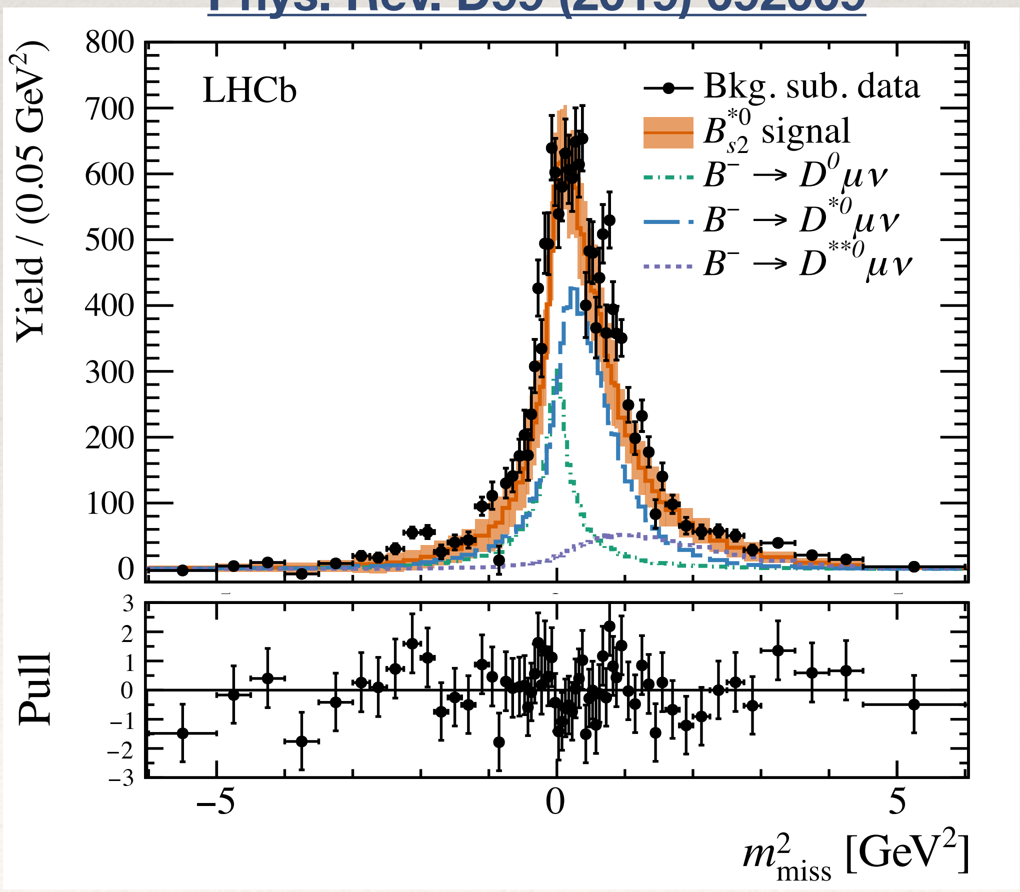
Idea: use B^*_{s2} to **tag** B^+ mesons

- use momentum of the kaon;
- mass constraints for B^*_{s2} and B^+;
- and their vertex constraints.

Energy of B^+ can be determined up to a quadratic ambiguity

- 2018: method used to measure the proportions of $D^0/D^{*0}/D^{**0}$ in semileptonic B^+ decays

Phys. Rev. D99 (2019) 092009



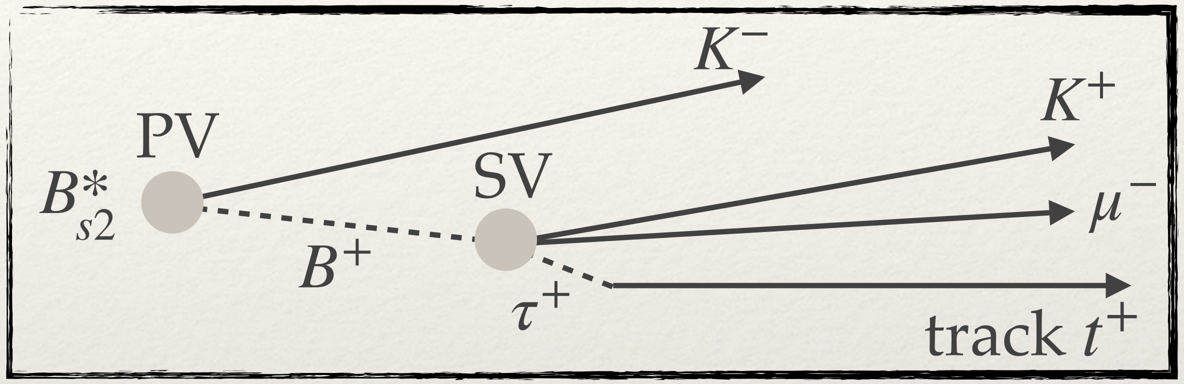
- 2020: search for decays with a $\tau^{\pm}$!

Search for $B^+ \to K^+\mu^-\tau^+$

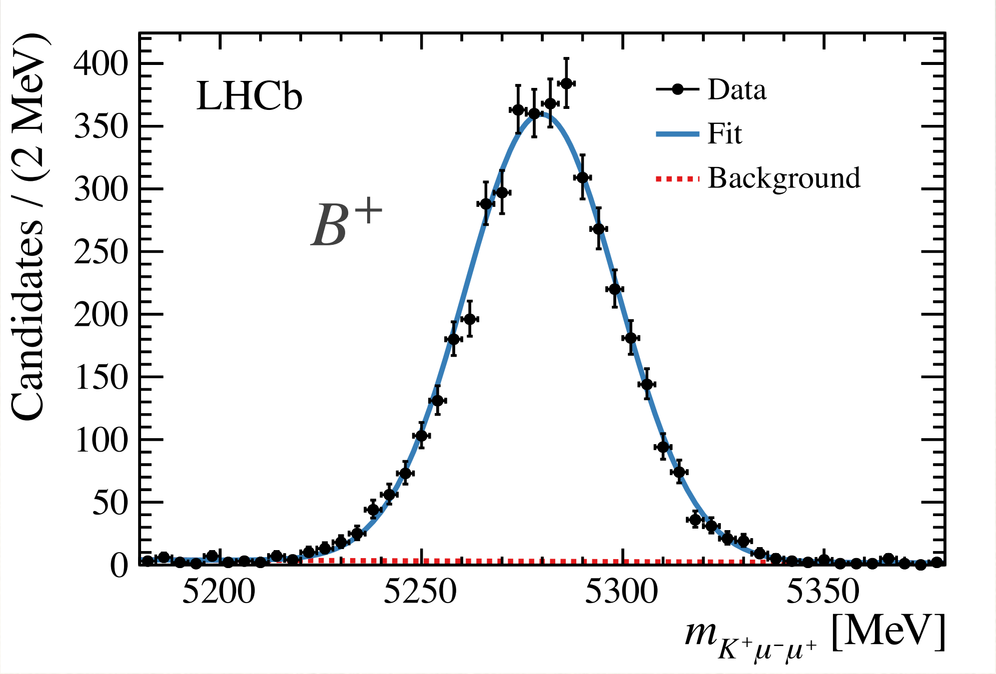
LHCb-PAPER-2019-043
arXiv:2003.04352
submitted to JHEP

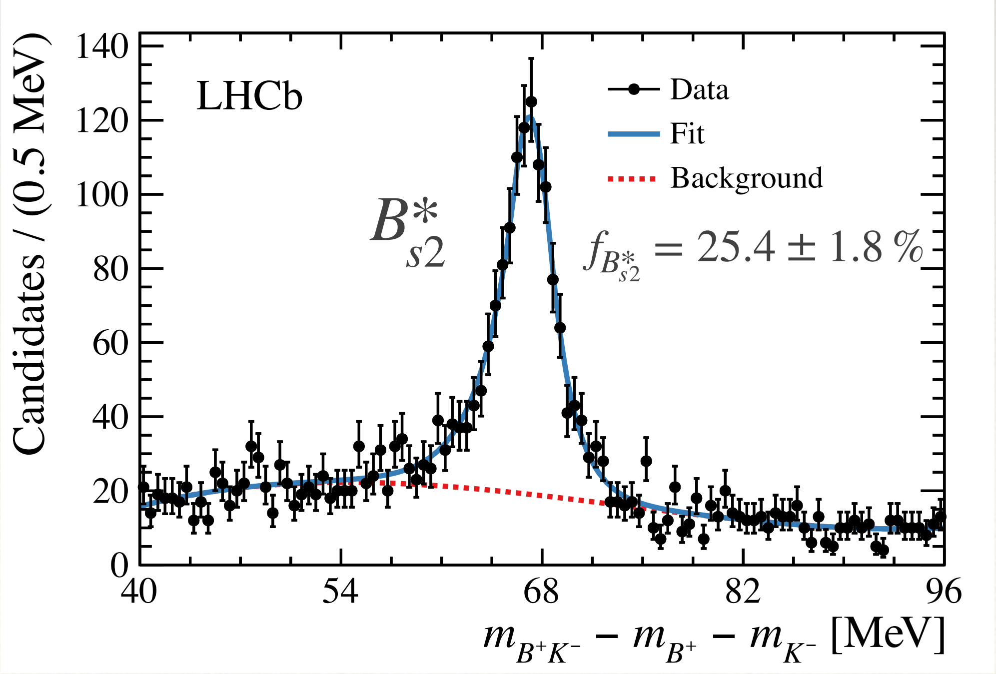
Dataset:
Run1, Run2
(9 fb[-1])

- Search for $B^+ \to K^+\mu^-\tau^+$ from B^*_{s2}
  - BaBar: $\mathscr{B}(B^+ \to K^+\mu^-\tau^+) < 2.8 \times 10^{-5}$ @ 90 % CL [PRD 86, 012004]
  - $B^+ \to K^+\mu^-\tau^+$ has **less background** from semileptonic $B \to \overline{D}\mu^+\nu_\mu X$ decays, than $B^+ \to K^+\mu^+\tau^-$
- **Sketch of the decay topology:**



- Inclusive selection of τ^+ decay to one track + X
  - require $m(K^+\mu^-t^+)_{t=\mu} < 4.8$ GeV to remove $B^+ \to K^+c\bar{c}(\mu^+\mu^-)$
- $B^+ \to K^+J/\psi(\mu^+\mu^-)$ used as **normalisation channel**

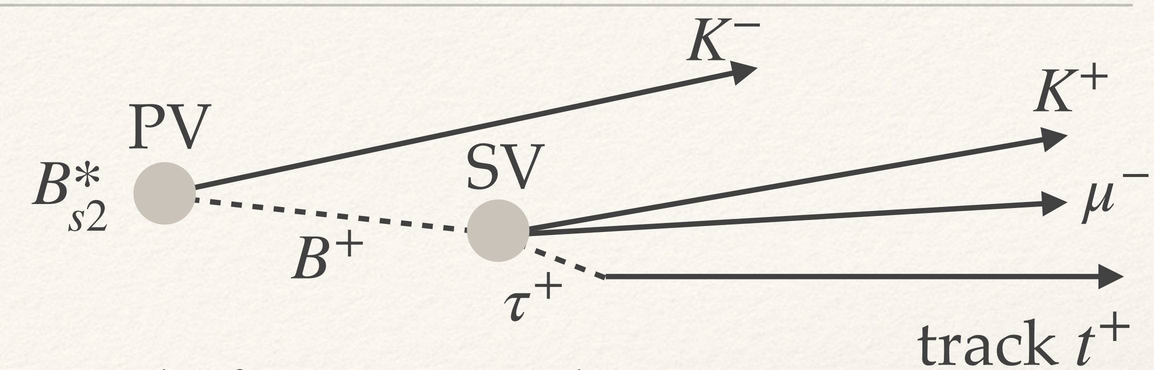




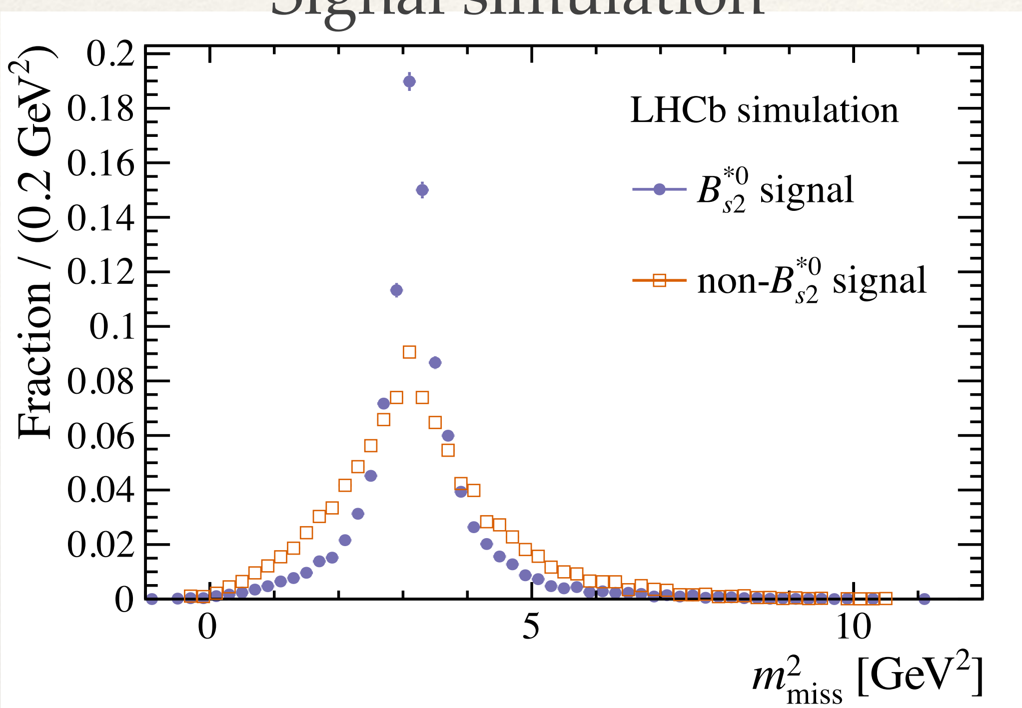
Background suppression

LHCb-PAPER-2019-043
arXiv:2003.04352
submitted to JHEP

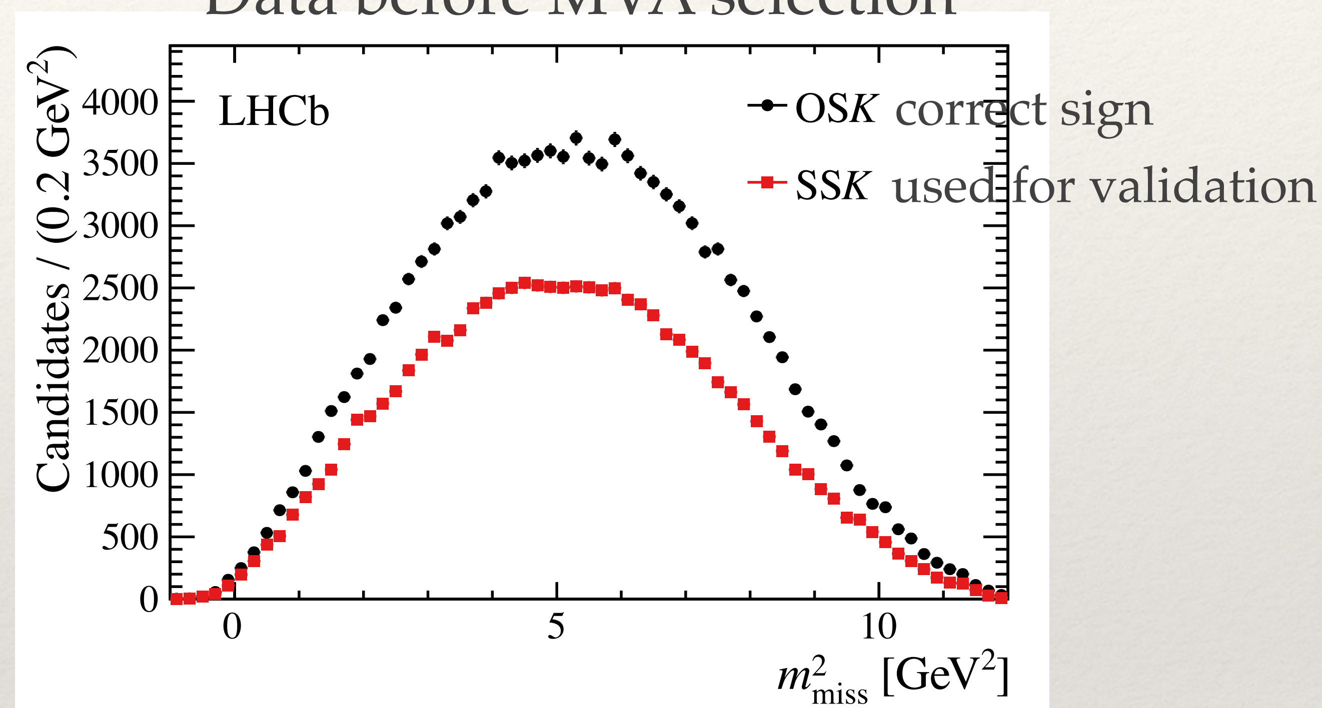
- Compute the missing mass



Signal simulation



Data before MVA selection

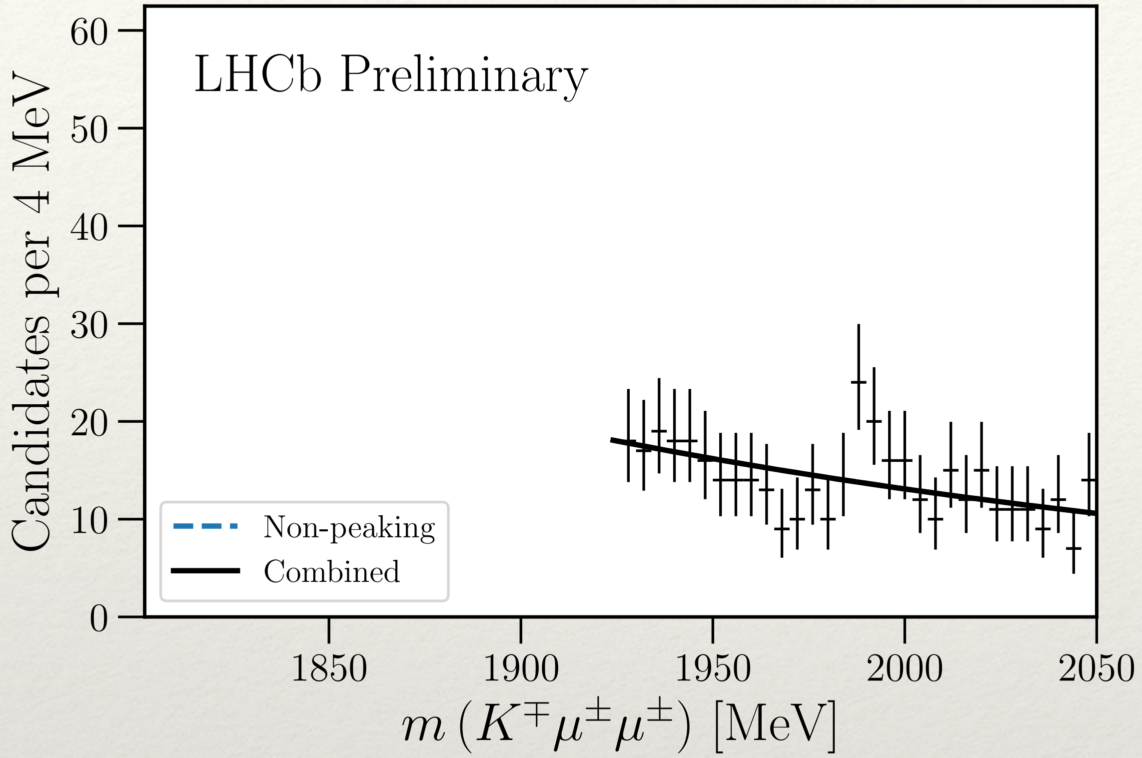


- Multivariate selection based on topology, two-body kinematics and flight distance of the tau (from momentum conservation)
- Background: mostly semileptonics
- **No peaking backgrounds** with $m^2_{miss} \sim m^2_\tau$
  - Processes of the kind $B^+ \to K^+\mu^-D^+$ do not exist in the SM

Search for 25 $D^+_{(s)} \to h\ell\ell$ modes

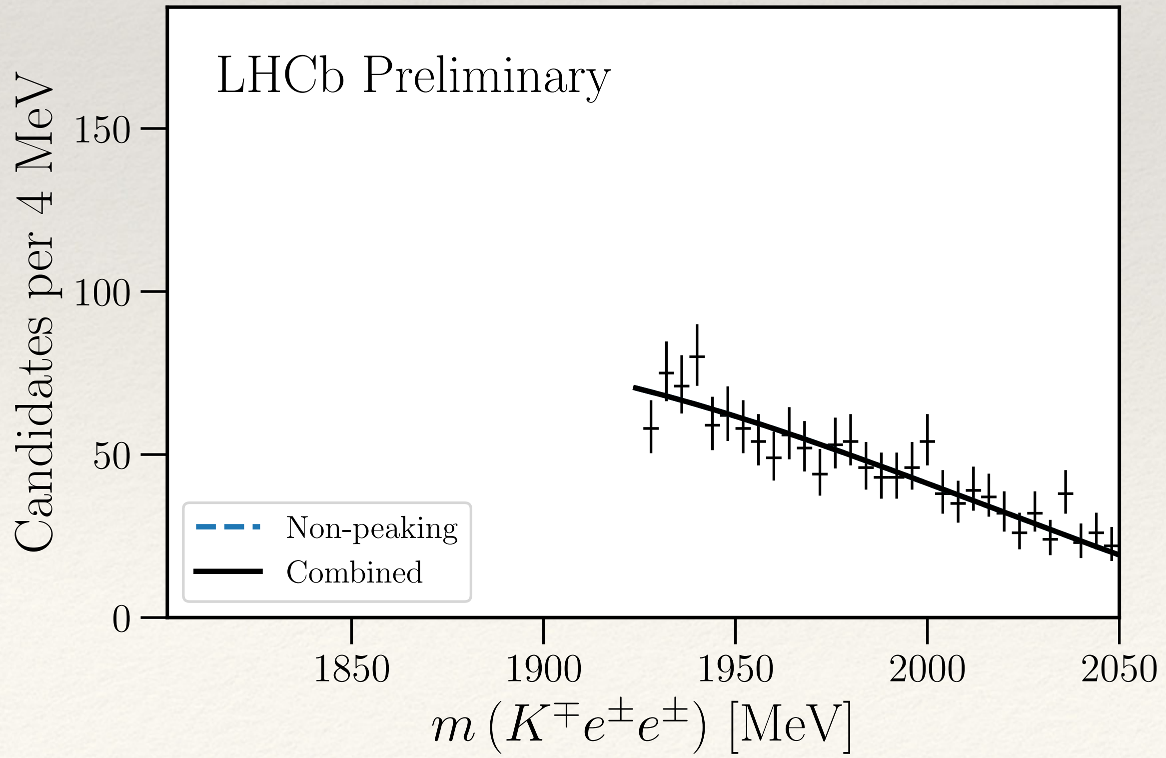
NEW!
LHCb-PAPER-2020-007
(in preparation)

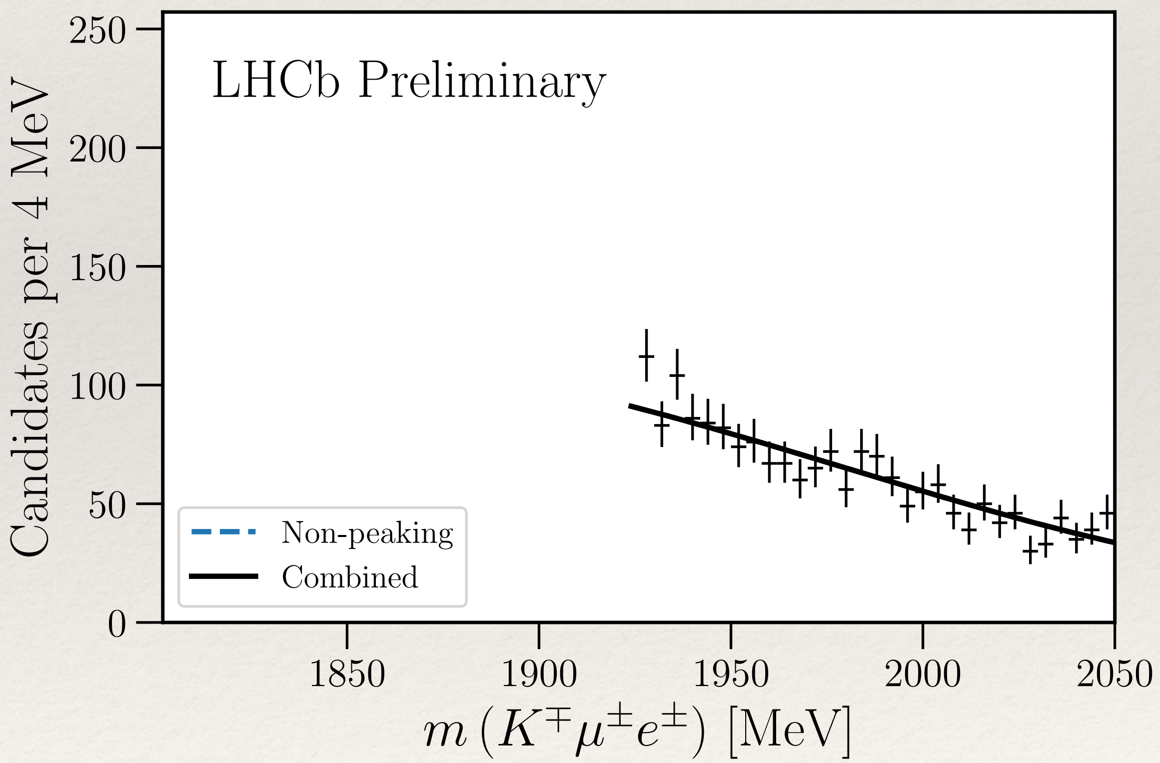
- $K^-\ell^+\ell^{(\prime)+}$ modes: only $D^+_s \to K^-\ell^+\ell^{(\prime)+}$ modes analysed



misidentified $D^+ \to K^+\pi^-\pi^-$
was found difficult to model,
3 $D^+ \to K^-\ell^+\ell^{(\prime)+}$ channels not analysed

will be followed up in the full Run 2 analysis

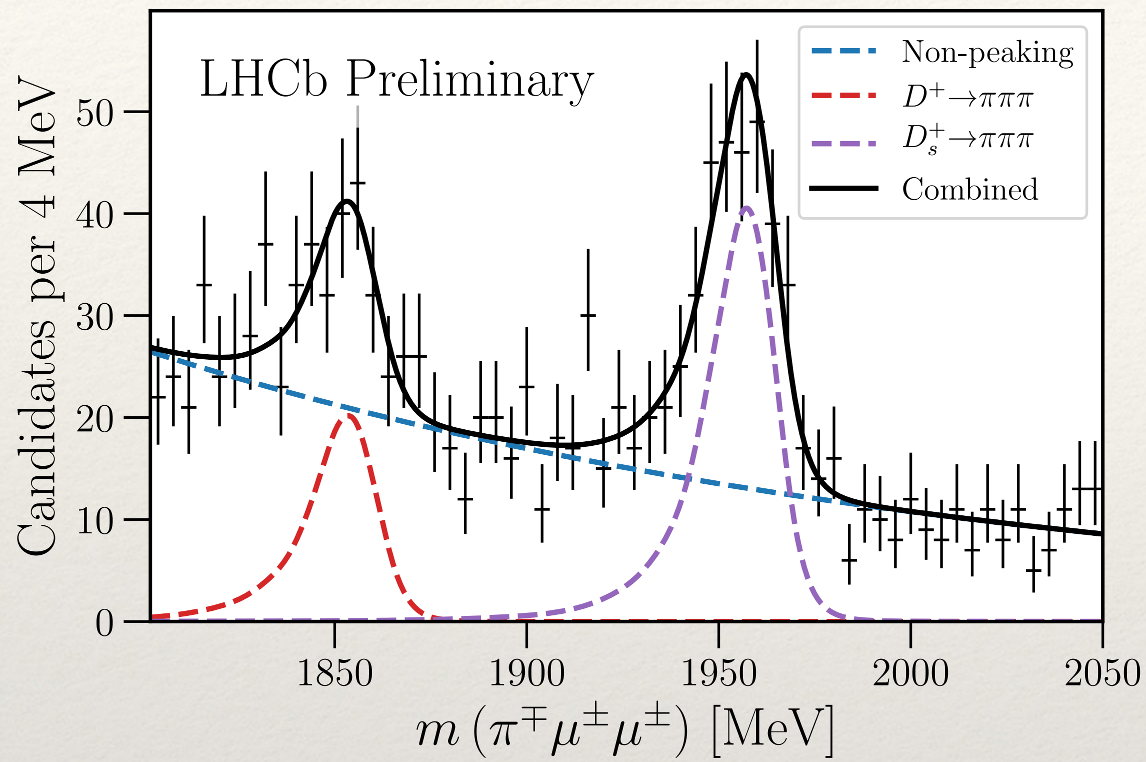


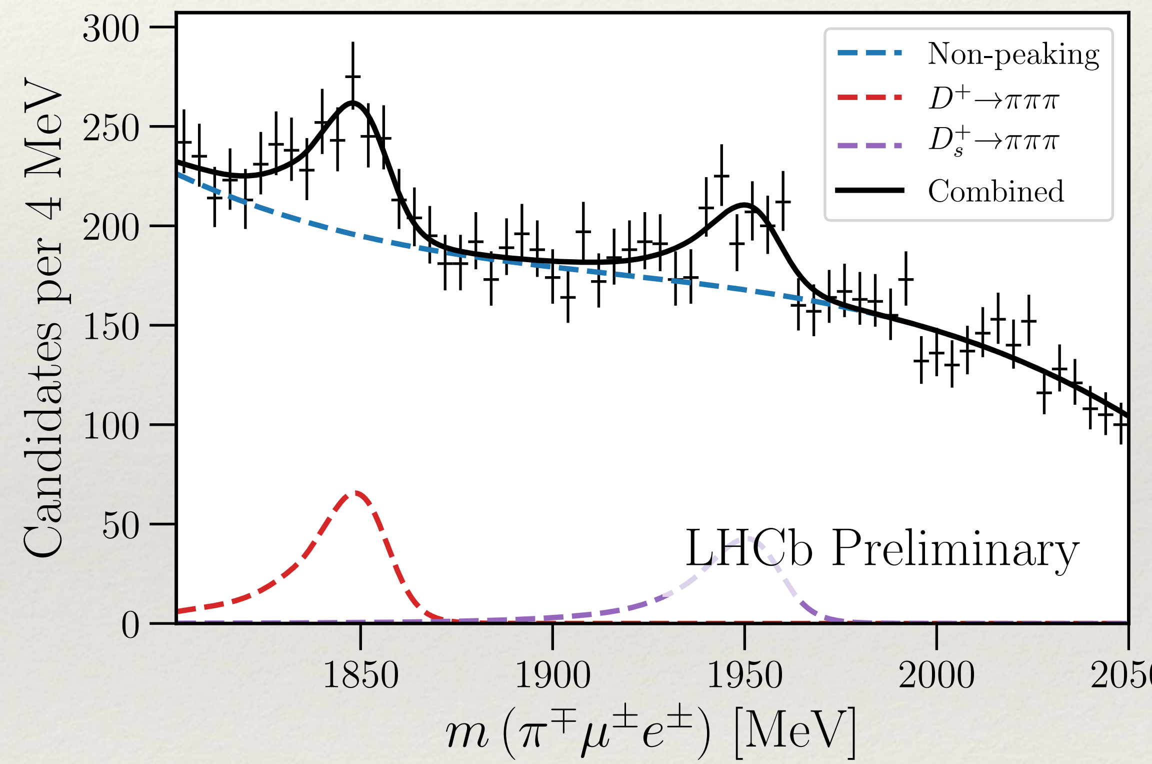


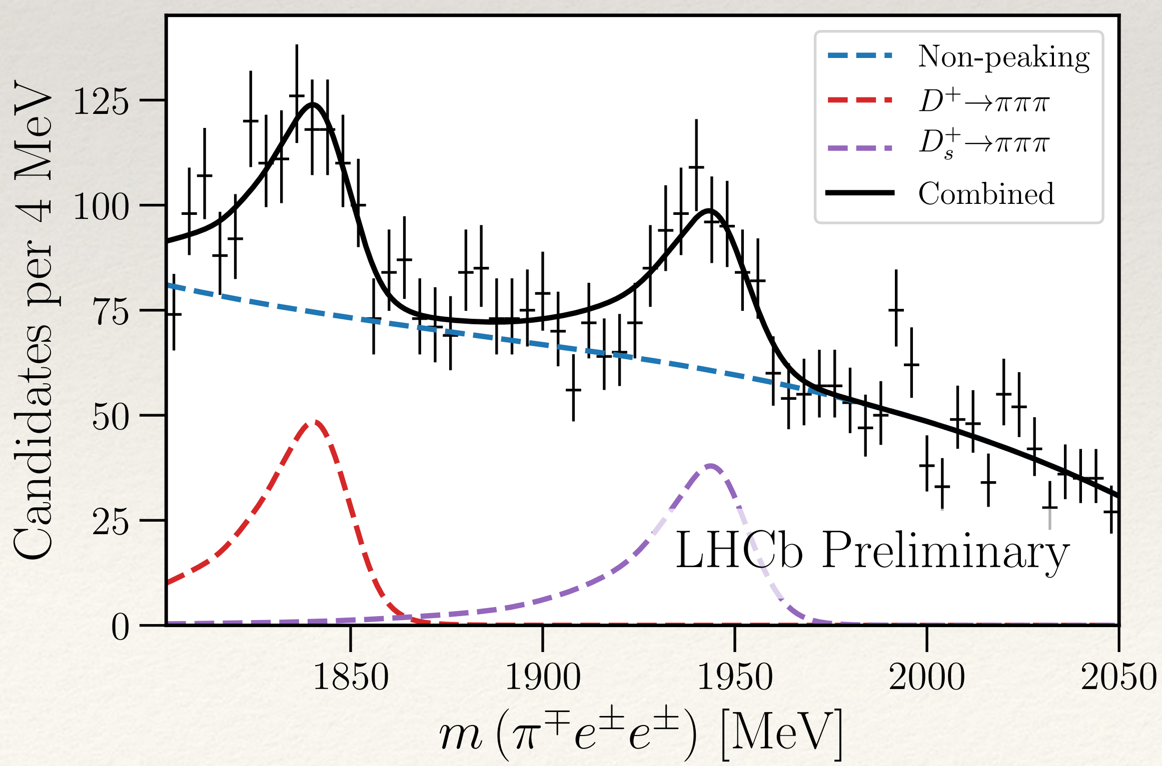
Search for 25 $D^+_{(s)} \to h\ell\ell$ modes

NEW!
LHCb-PAPER-2020-007
(in preparation)

- $\pi^-\ell^+\ell^{(\prime)+}$ modes: large misID backgrounds under control



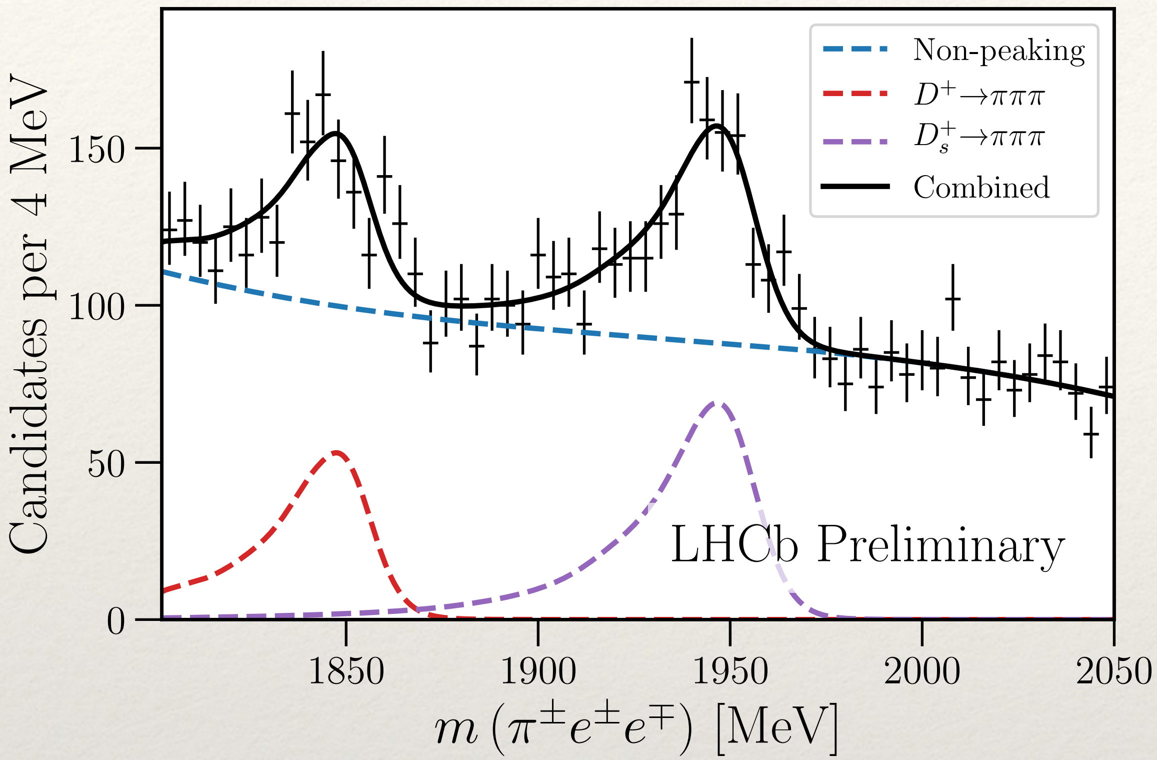


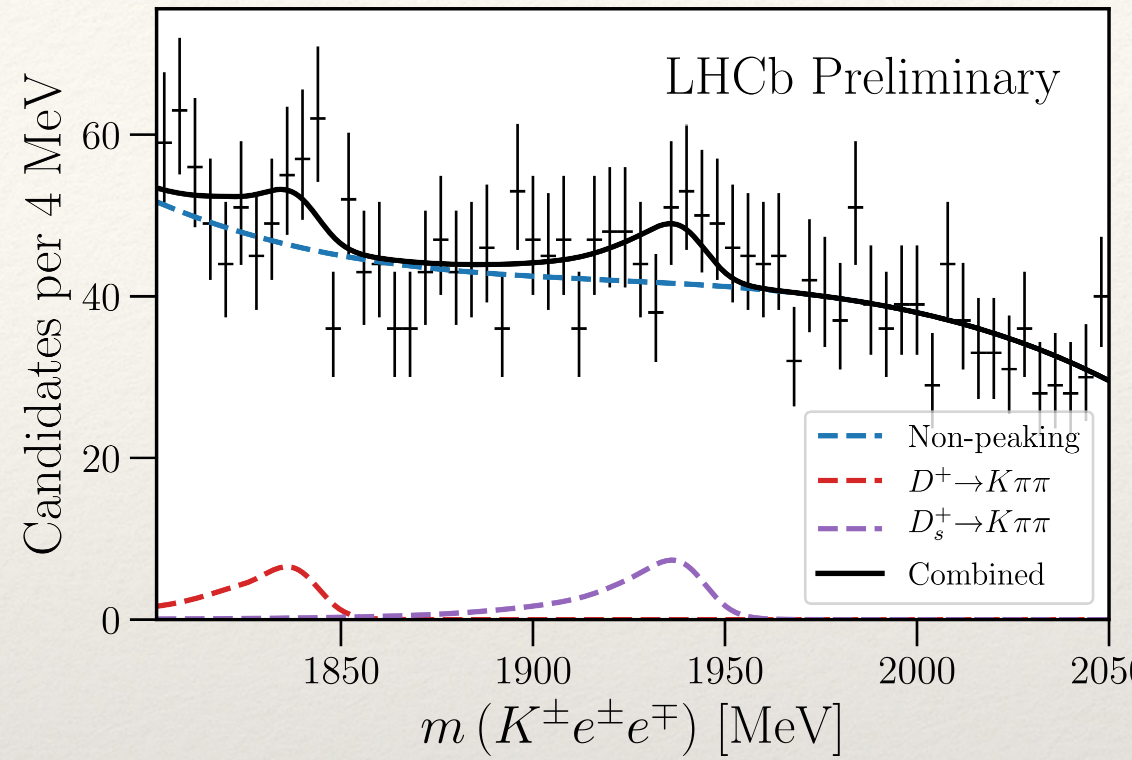


Search for 25 $D^+_{(s)} \to h\ell\ell$ modes

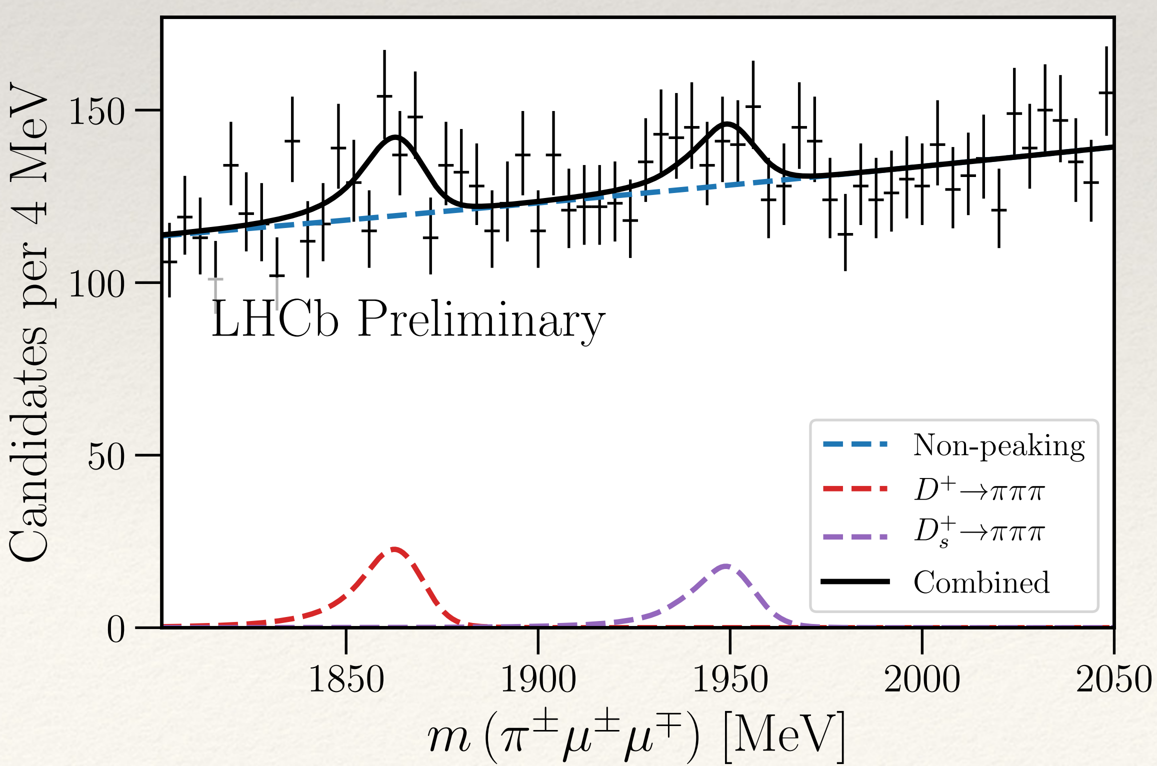
NEW!
LHCb-PAPER-2020-007
(in preparation)

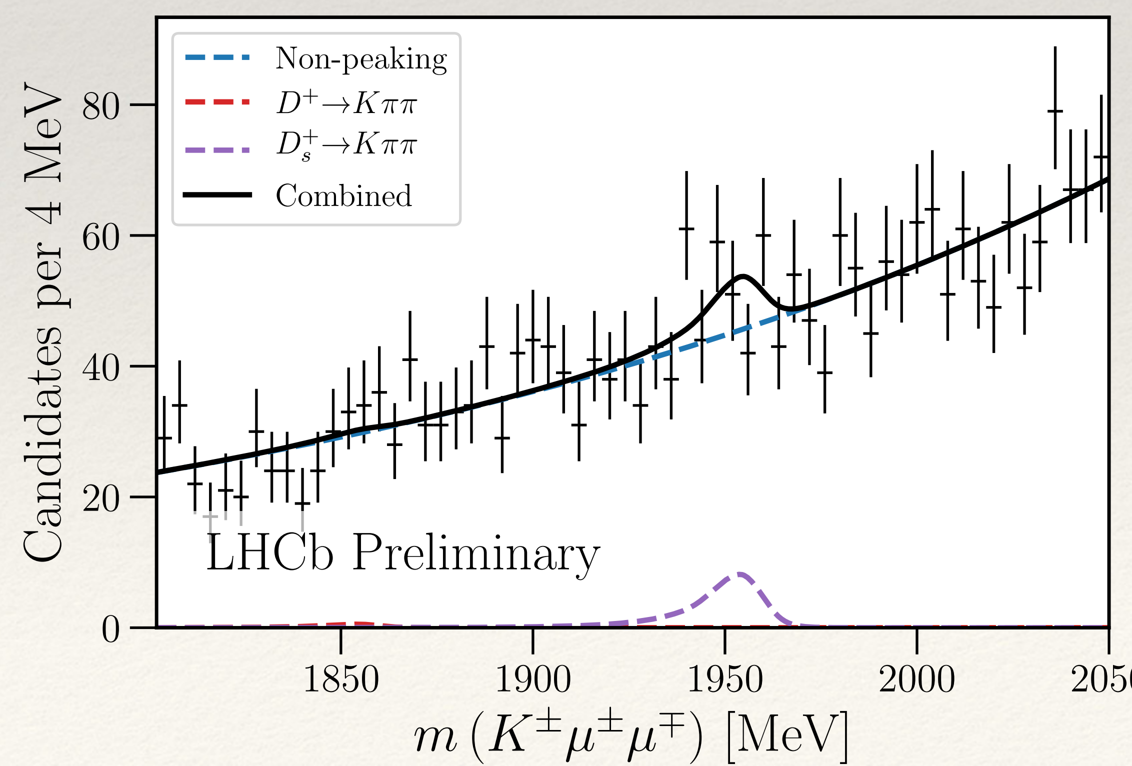
- $h^+e^+e^-$ and $h^+\mu^+\mu^-$ modes





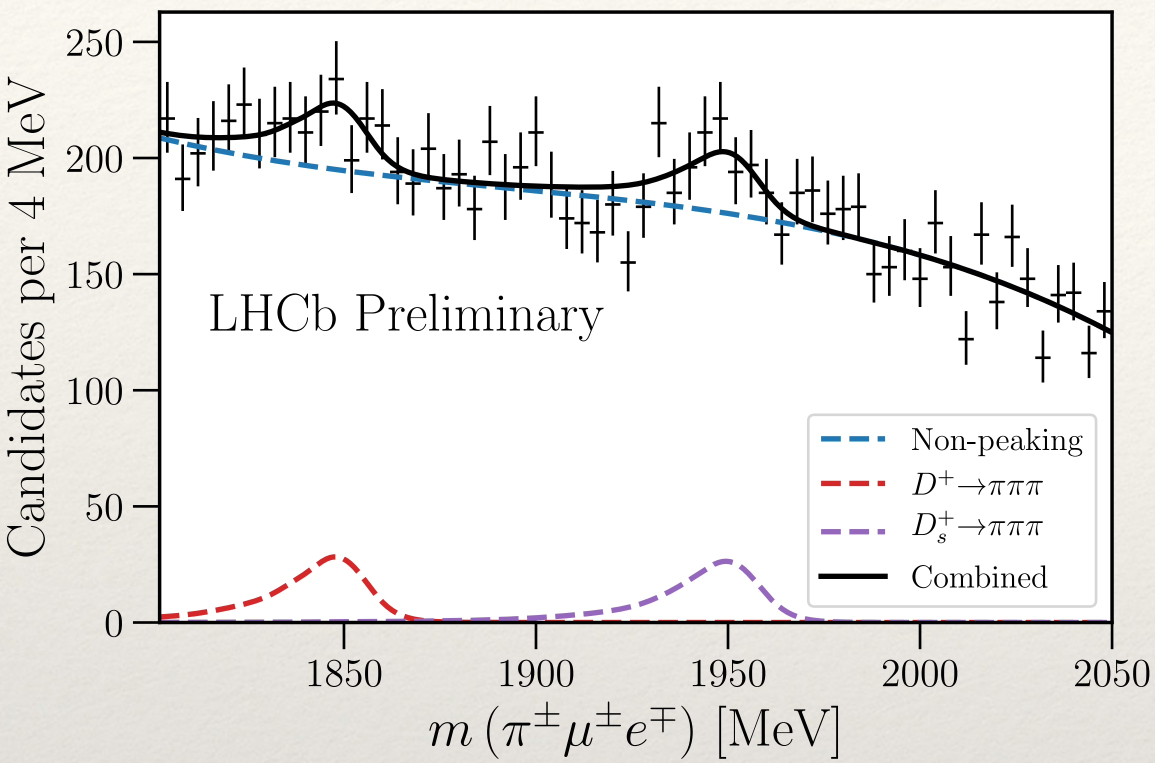
Two plots below were shown in the main body of the talk

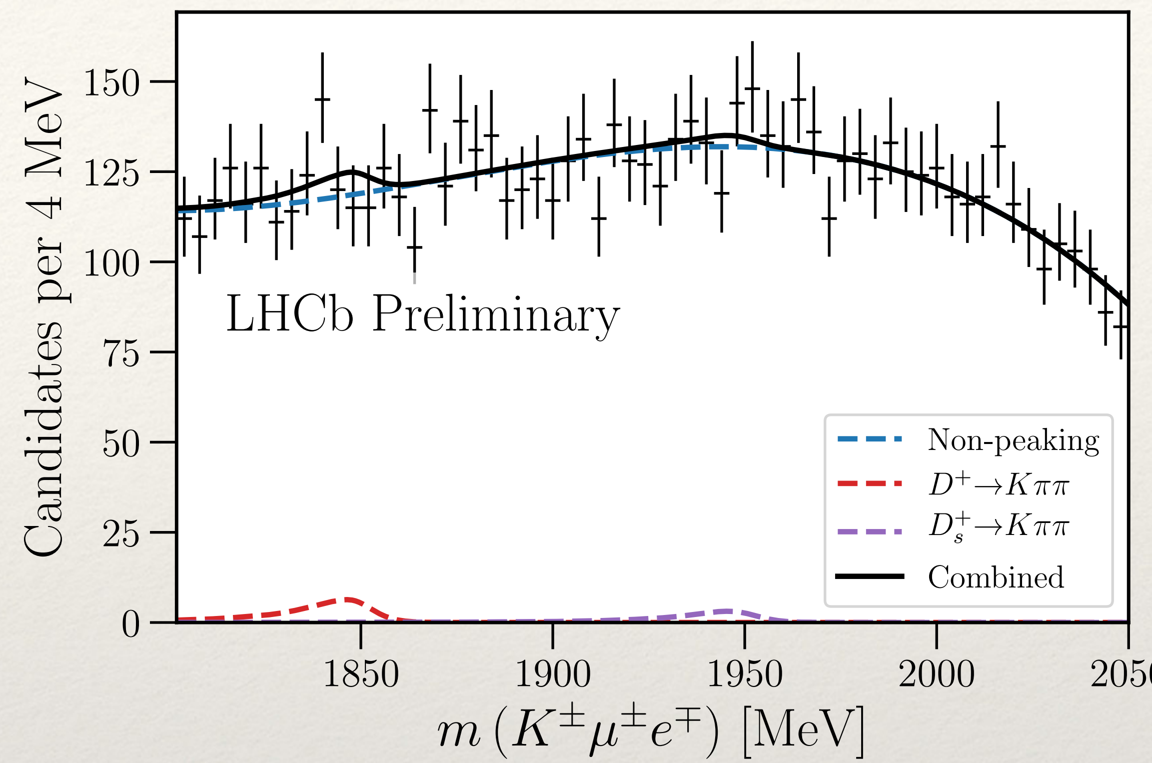




Search for 25 $D^+_{(s)} \to h\ell\ell$ modes

- Opposite-sign LFV modes





Two plots below were shown in the main body of the talk