OVERVIEW OF LEPTON FLAVOR VIOLATING DECAYS AT LHCb

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Novel aspects of *b* to *s* transitions
Marseille, 5-7 October 2015

OUTLINE

- The experimental challenges in the search for LFV decays in LHCb.
- LFV searches performed at LHCb
  (not strictly in the context of *b->sll* transitions)
- Tests of lepton flavor universality: R_K and R_{D^*}
- Plans for searches of *b->sll* LFV decays.

LFV DECAYS IN LHCb: THE CHALLENGES

Trigger: needs to be efficient for the decay under study
(easy to trigger on muons, more difficult on electrons)

Reconstruction: e and τ reconstruction in a hadronic environment is complicated

"Stripping" : this preselection of the LHCb data is periodically run on data and needs to be well tuned to be efficient:

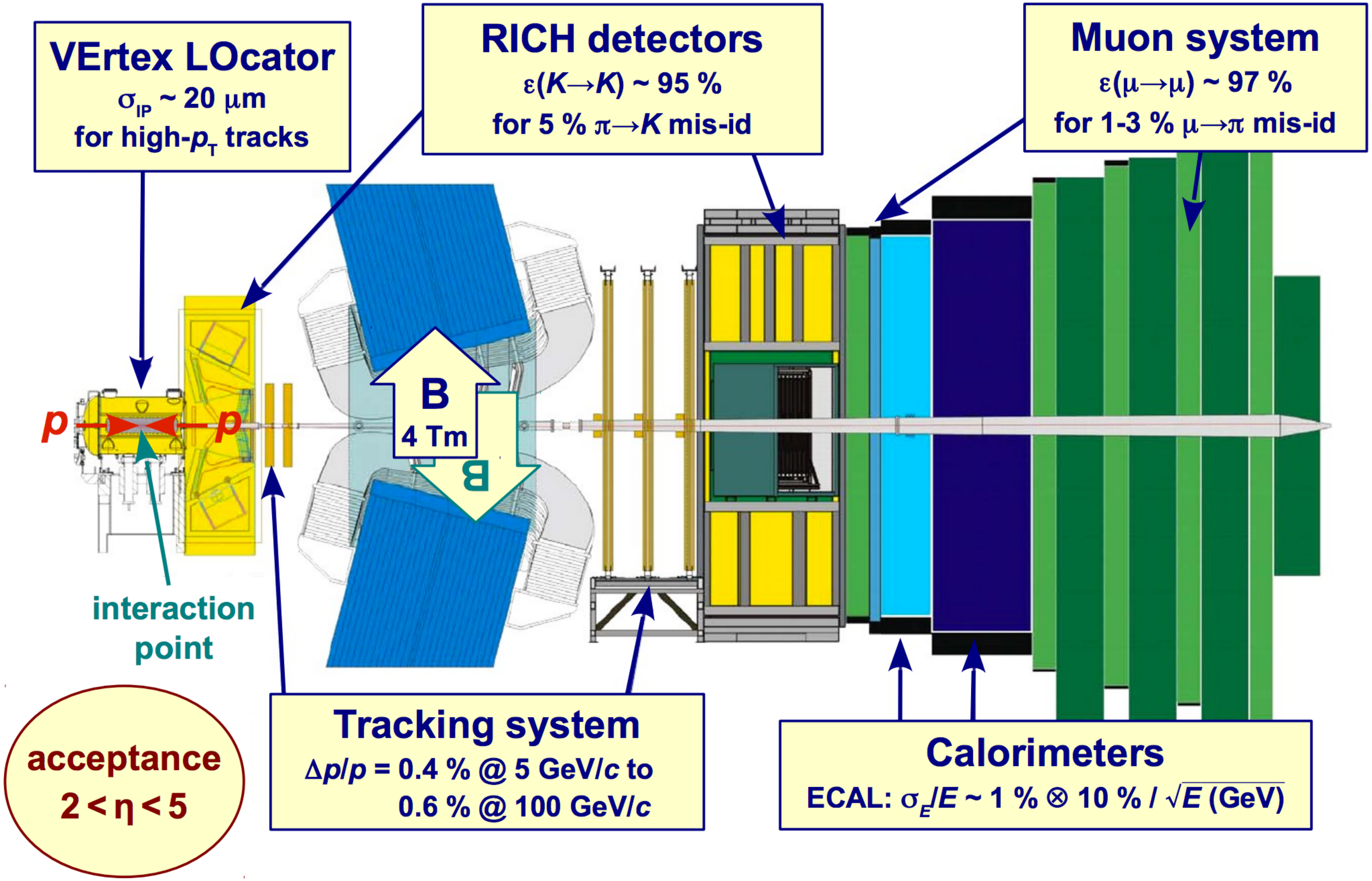
- some LFV channels are already feasible
- others needs a data re-stripping => time delay

Combinatorial backgrounds: reduced exploiting a large set of kinematic variables
Peaking and partially reconstructed backgrounds:

- largest contribution if bad mass resolution
- sometimes complicated to identify, as simulations have a limited size and can not include all possible decays
- more complicated to reduce and to correctly model

At the moment we are elaborating the best strategies to face these issues in the context of LFV B decays

THE LHCb DETECTOR

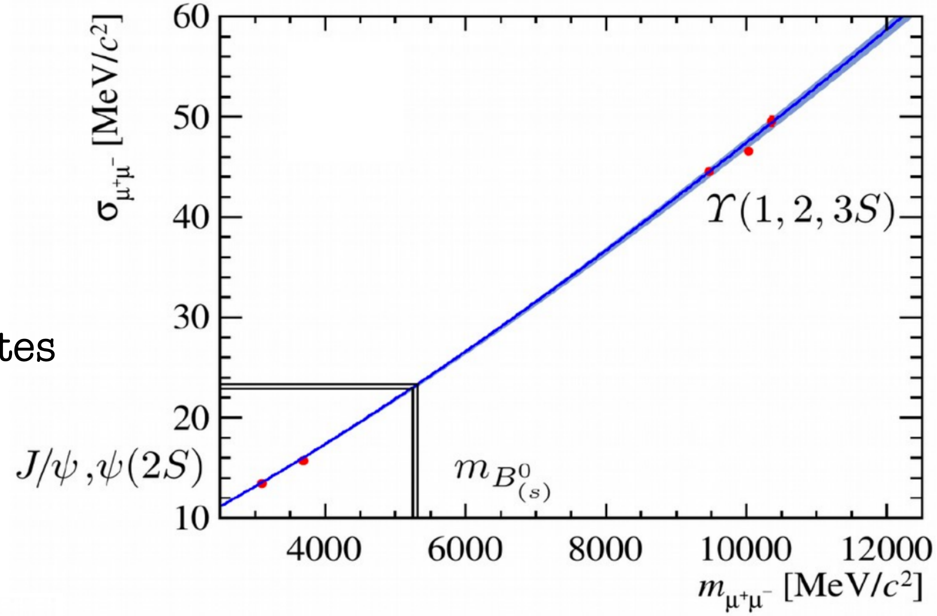


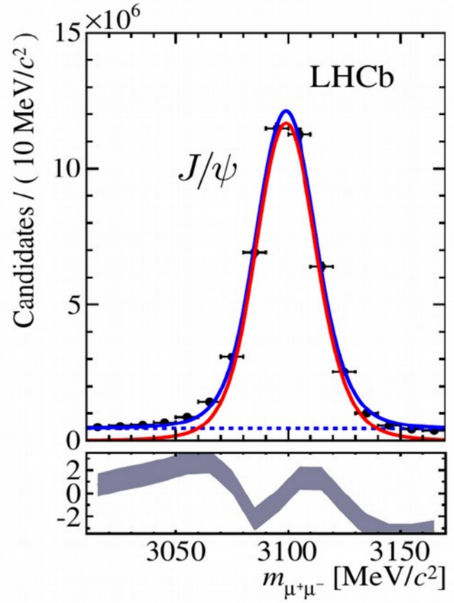
MUONS RECONSTRUCTION

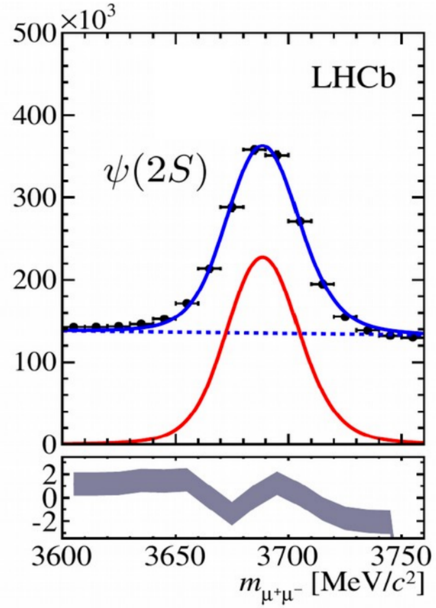
- Extremely performing in LHCb:
  - dedicated muon chambers
  - very efficient tracking system.

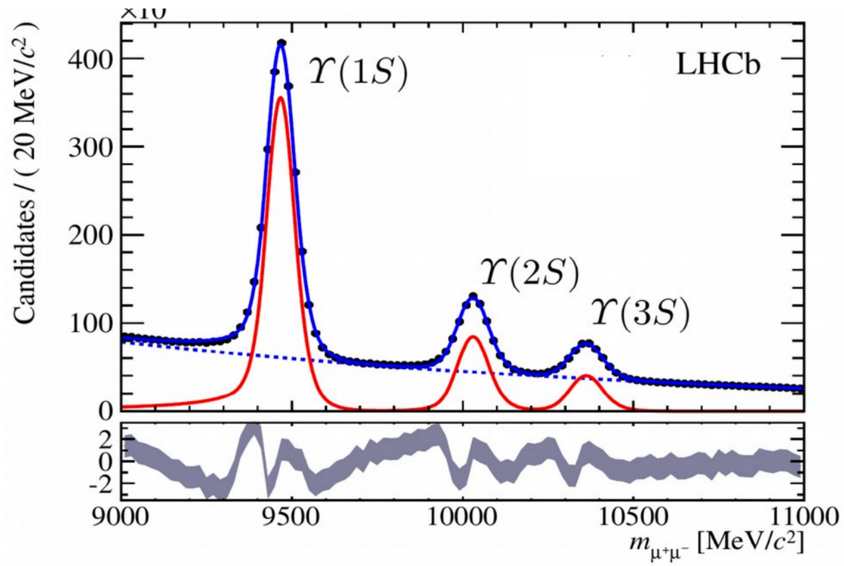
- A muon is a clear trigger signature:
  ε(L0+HLT)= ~90% for di-muon channels
  ε(L0+HLT)= ~30% for multibody hadronic states

- Very good di-muon resolution



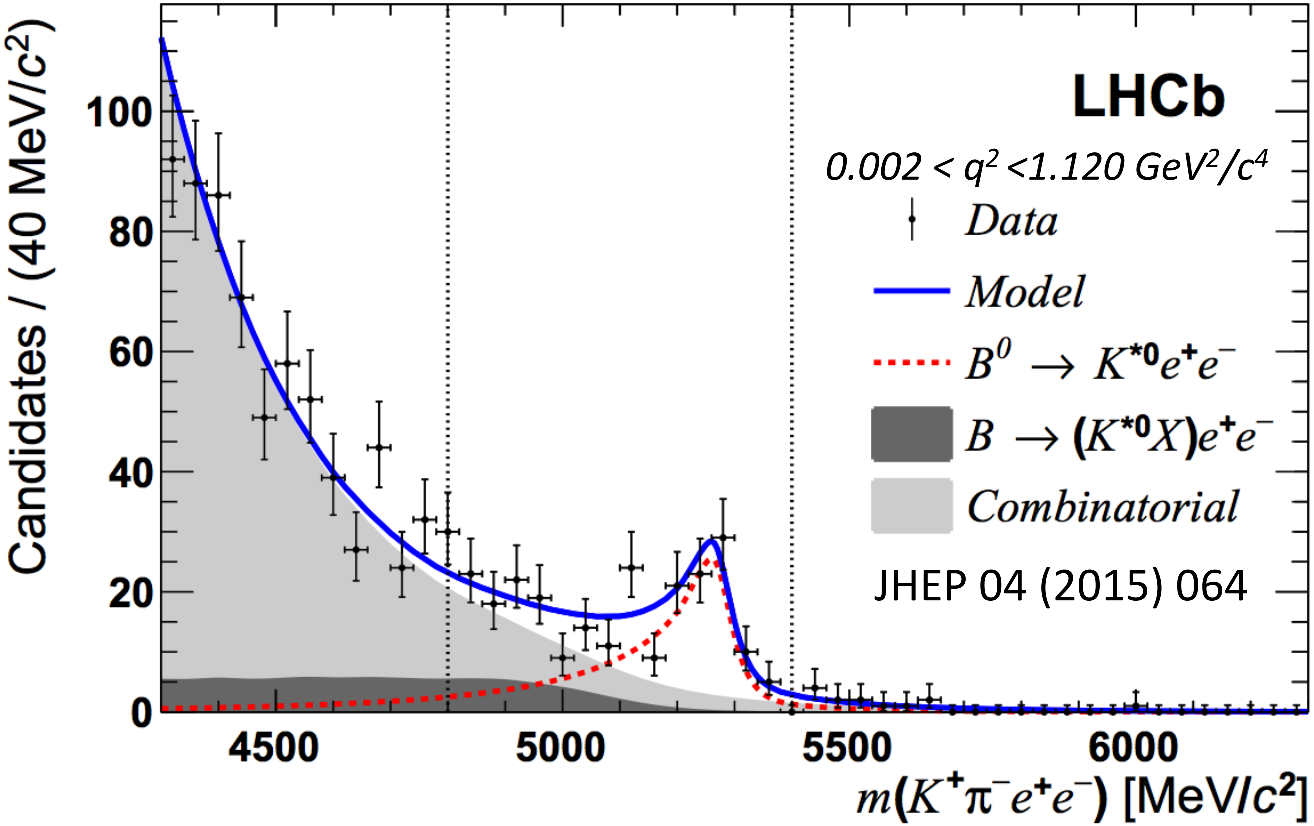






ELECTRON RECONSTRUCTION

- Identified through the electromagnetic calorimeter ➔ $ECAL: \frac{\sigma_E}{E} \sim 1\% \otimes \frac{10\%}{\sqrt{E(GeV)}}$
- Resolution degraded by energy loss from Bremsstrahlung:
  - recovery of Bremsstrahlung photons can not be 100% efficient
  - significant degradation of the *B* mass resolution with a tail on the left

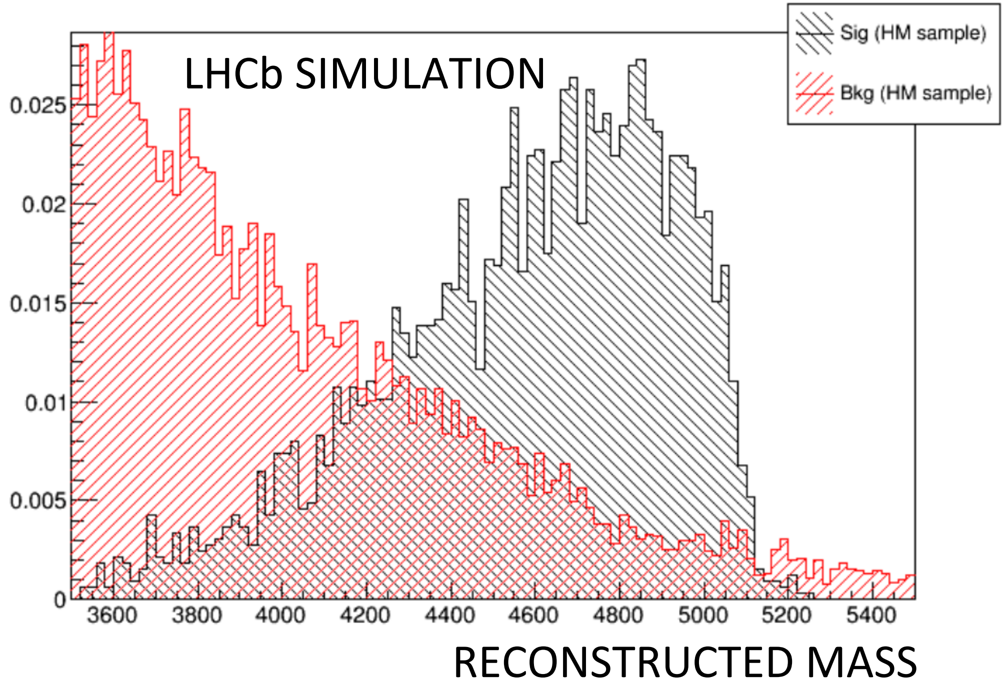


TAU RECONSTRUCTION

- Taus reconstructed through their decays.
- Accompanied by neutrinos: missing energy and degradation of the B mass resolution
- Tau decay vertex not always identified
- Traditional and new reconstruction techniques based on the kinematics are explored (see also talk from Alessandro Morda)

Leptonic:
- $BR(\tau^- \to \mu^- \nu\nu) = 17.41 \pm 0.04$ %
- $BR(\tau^- \to e^- \nu\nu) = 17.83 \pm 0.04$ %

Hadronic:
- $BR(\tau^- \to \pi^- \nu) = 10.83 \pm 0.06$ %
- $BR(\tau^- \to \pi^- \pi^0 \nu) = 25.52 \pm 0.09$ %
- $BR(\tau^- \to \pi^- \pi^0 \pi^0 \nu) = 9.30 \pm 0.11$ %
- $BR(\tau^- \to \pi^- \pi^+ \pi^- \nu) = 9.31 \pm 0.06$ %
- $BR(\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu) = 4.62 \pm 0.06$ %



CONTROL CHANNELS

- Control channels are decays with a final state as much similar as possible to the one under study.

- They are crucial in LHCb analysis:
  - to provide validation/correction for the shapes of the discriminating variables obtained from the simulations
  - to be used as normalization channels to cancel lots of systematic uncertainties

$\tau^- \rightarrow \mu^-\mu^+\mu^-$

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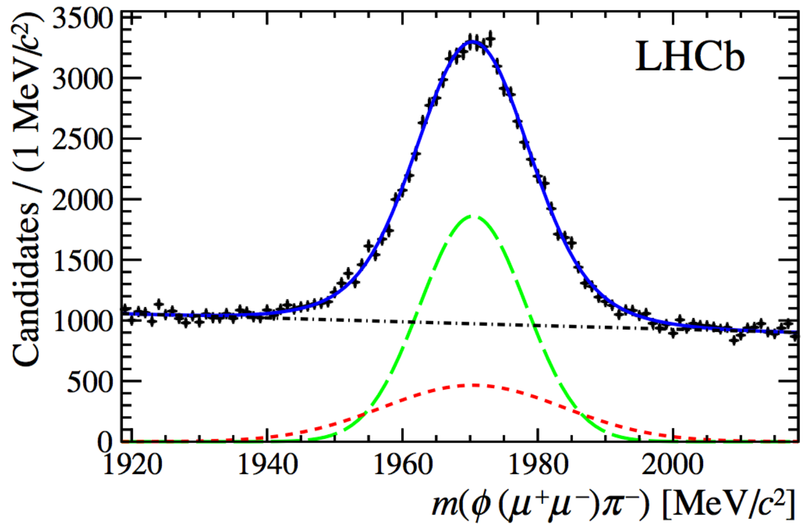
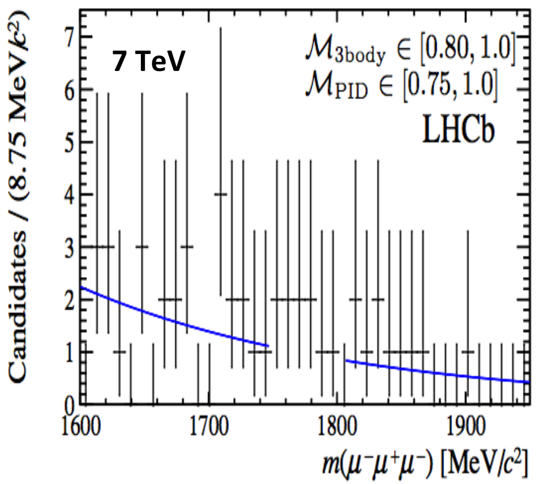
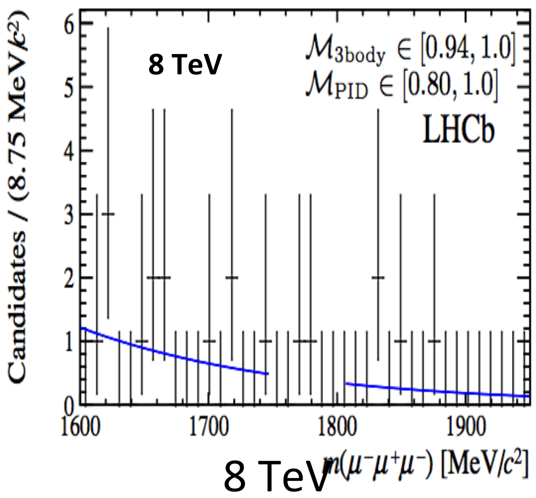
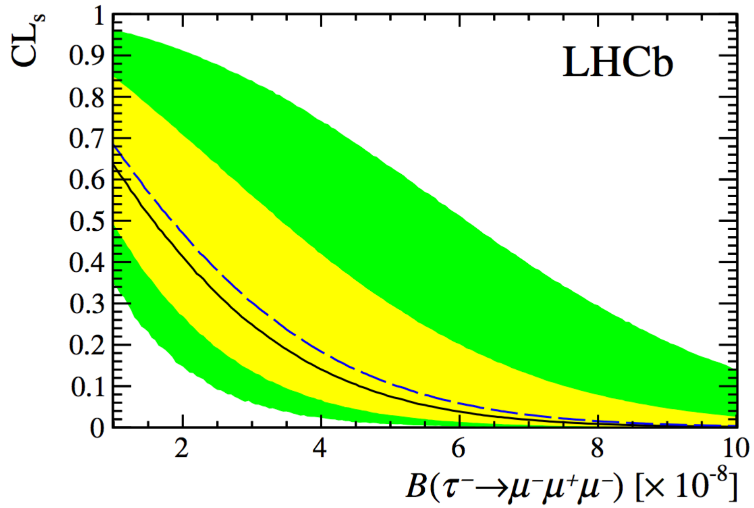
- First measurement of such decay at hadron collider
- Based on 3 fb^{-1}
- Exploiting excellent muon resolution
- Control and normalization channel: $D_s \to \phi(\mu\mu)\pi$
- Belle: $B(\tau^- \rightarrow \mu^-\mu^+\mu^-) < 2.1\times10^{-8}$ @ 90% CL
  BaBar: $B(\tau^- \rightarrow \mu^-\mu^+\mu^-) < 3.3\times10^{-8}$ @ 90% CL
  LHCb: $B(\tau^- \rightarrow \mu^-\mu^+\mu^-) < 4.6\times10^{-8}$ @ 90% CL



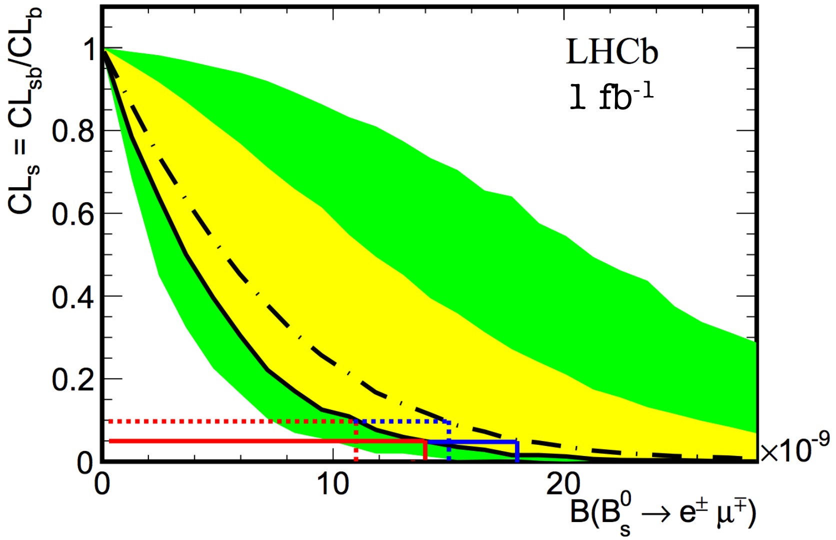


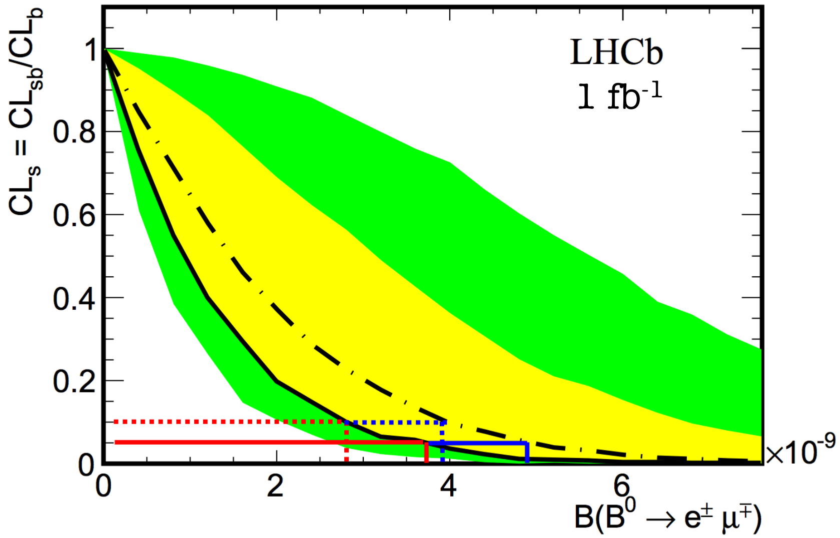




$B \to e\,\mu$

BDT bin	0.0 – 0.25	0.25 – 0.4	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 – 0.8	0.8 – 0.9	0.9 – 1.0
Expected bkg (from fit)	2222 ± 51	$80.9^{+10.1}_{-9.4}$	$20.4^{+5.0}_{-4.5}$	$13.2^{+3.9}_{-3.6}$	$2.1^{+2.9}_{-1.4}$	$3.1^{+1.9}_{-1.4}$	$3.1^{+1.9}_{-1.4}$	$1.7^{+1.4}_{-1.0}$
Expected $B^0_{(s)} \to h^+h'^-$ bkg	0.67±0.12	0.47±0.09	0.40±0.08	0.37±0.06	0.45±0.08	0.49±0.08	0.57±0.09	0.54±0.12
Observed	2332	90	19	4	3	3	3	1





Mode	Limit	90 % C.L.	95 % C.L.
$B^0_s \to e^\pm\mu^\mp$	Expected	1.5×10^{-8}	1.8×10^{-8}
	Observed	1.1×10^{-8}	1.4×10^{-8}
$B^0 \to e^\pm\mu^\mp$	Expected	3.8×10^{-9}	4.8×10^{-9}
	Observed	2.8×10^{-9}	3.7×10^{-9}

Limits on Pati-Salam leptoquark model:

- $M_{LQ}(B_s \to e\mu) > 101$ TeV/c^2 @95%CL
- $M_{LQ}(B_d \to e\mu) > 126$ TeV/c^2 @95%CL

THE R_K MEASUREMENT

PRL 113, 151601 (2014)

$$R_K = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{{\rm d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{{\rm d}q^2}{\rm d}q^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{{\rm d}\Gamma[B^+ \to K^+e^+e^-]}{{\rm d}q^2}{\rm d}q^2}$$

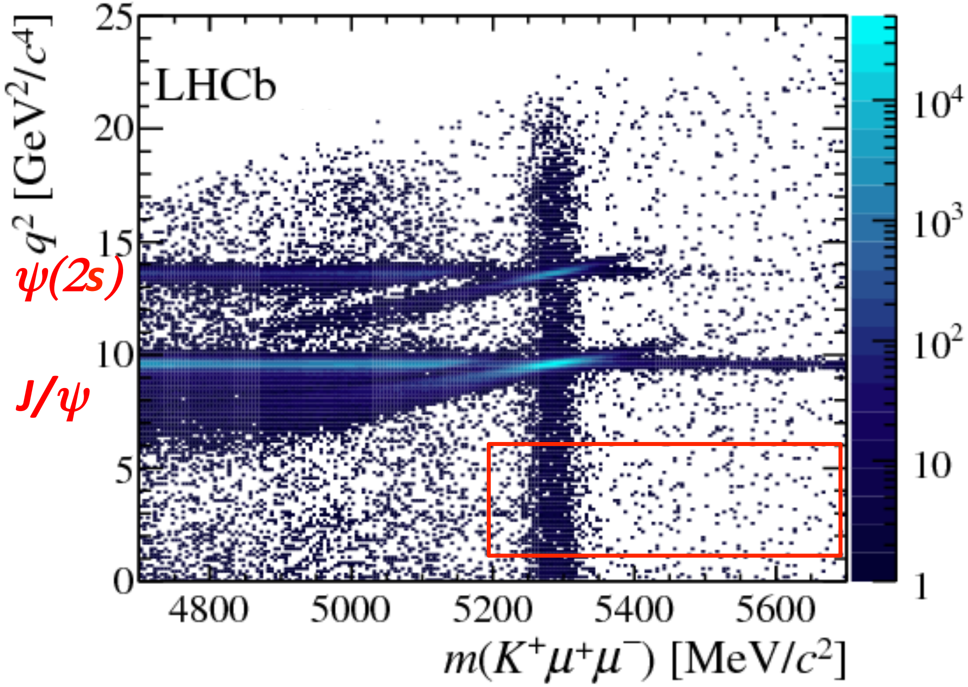
- Expected to be 1 in the Standard Model (lepton flavor universality)
- Theoretical uncertanty ~10^{-3}
- Analysis on the whole run1 dataset: 3 fb^{-1}, in the q^2 range [1, 6] GeV^2/c^4
- Use the double ratio of the rare to the J/ψ channel to reduce systematics:

$$R_K = \left(\frac{\mathcal{N}_{K^+\mu^+\mu^-}}{\mathcal{N}_{K^+e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi(e^+e^-)K^+}}{\mathcal{N}_{J/\psi(\mu^+\mu^-)K^+}}\right)\left(\frac{\epsilon_{K^+e^+e^-}}{\epsilon_{K^+\mu^+\mu^-}}\right)\left(\frac{\epsilon_{J/\psi(\mu^+\mu^-)K^+}}{\epsilon_{J/\psi(e^+e^-)K^+}}\right)$$

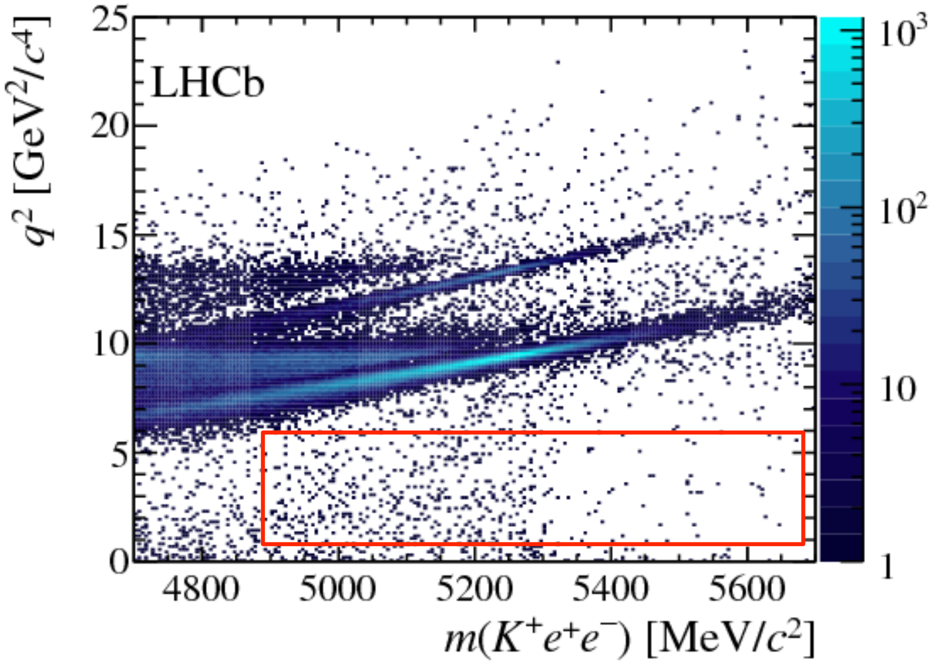
R_K : THE DATASET

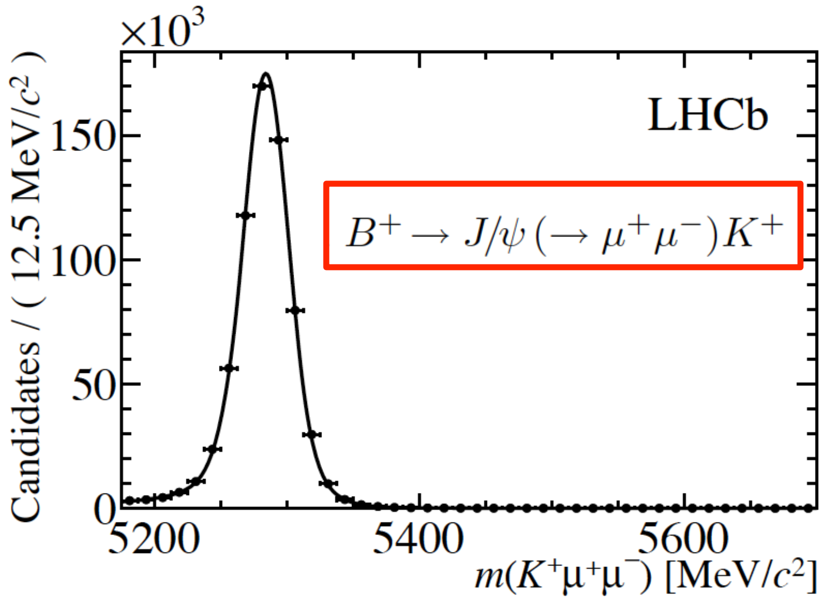
PRL 113, 151601 (2014)

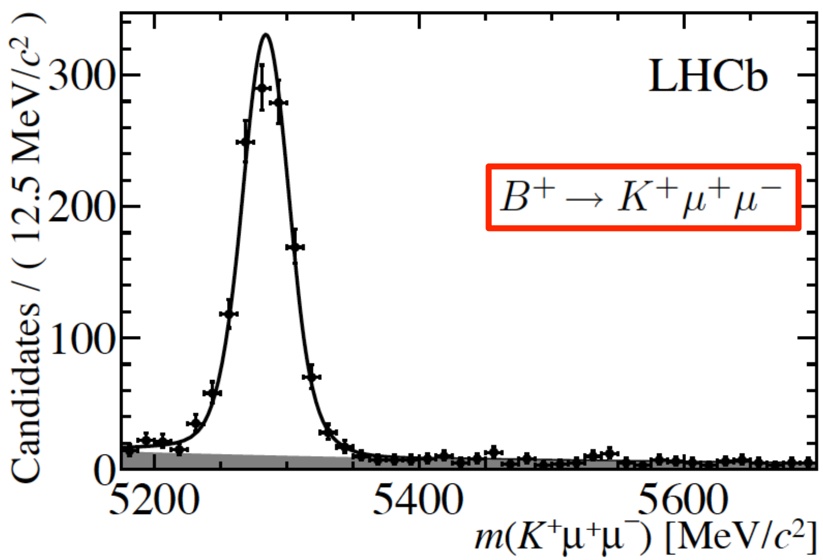
Muon channel



Electron channel

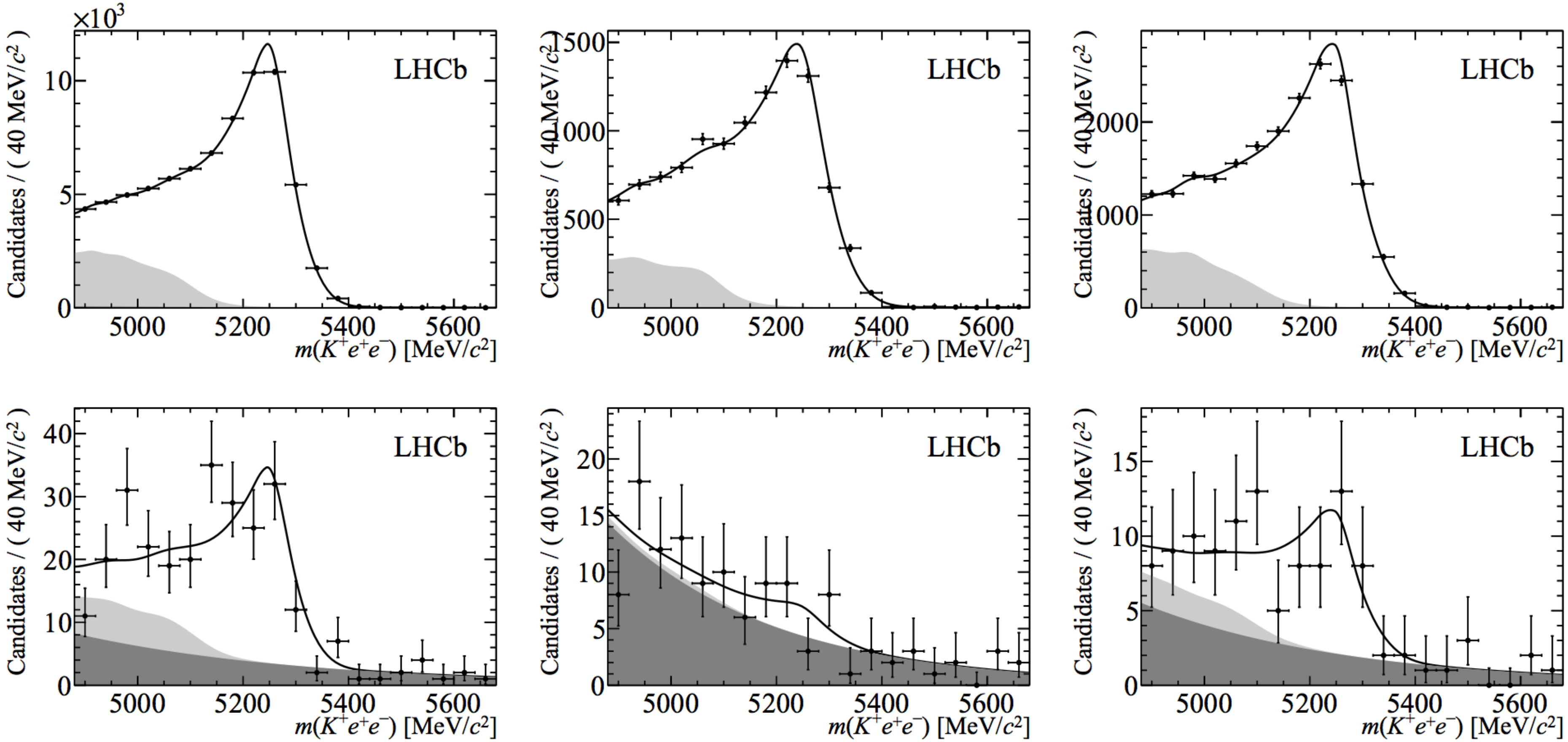






- Excellent resolution
- Extremely clean

Triggered from one electron | Triggered from kaon | Triggered from other particles



- Important Bremsstrahlung contribution (0-Brem: 37%, 1-Brem: 48%, 2-Brem:15%)
- Larger backgrounds

R_K : RESULTS

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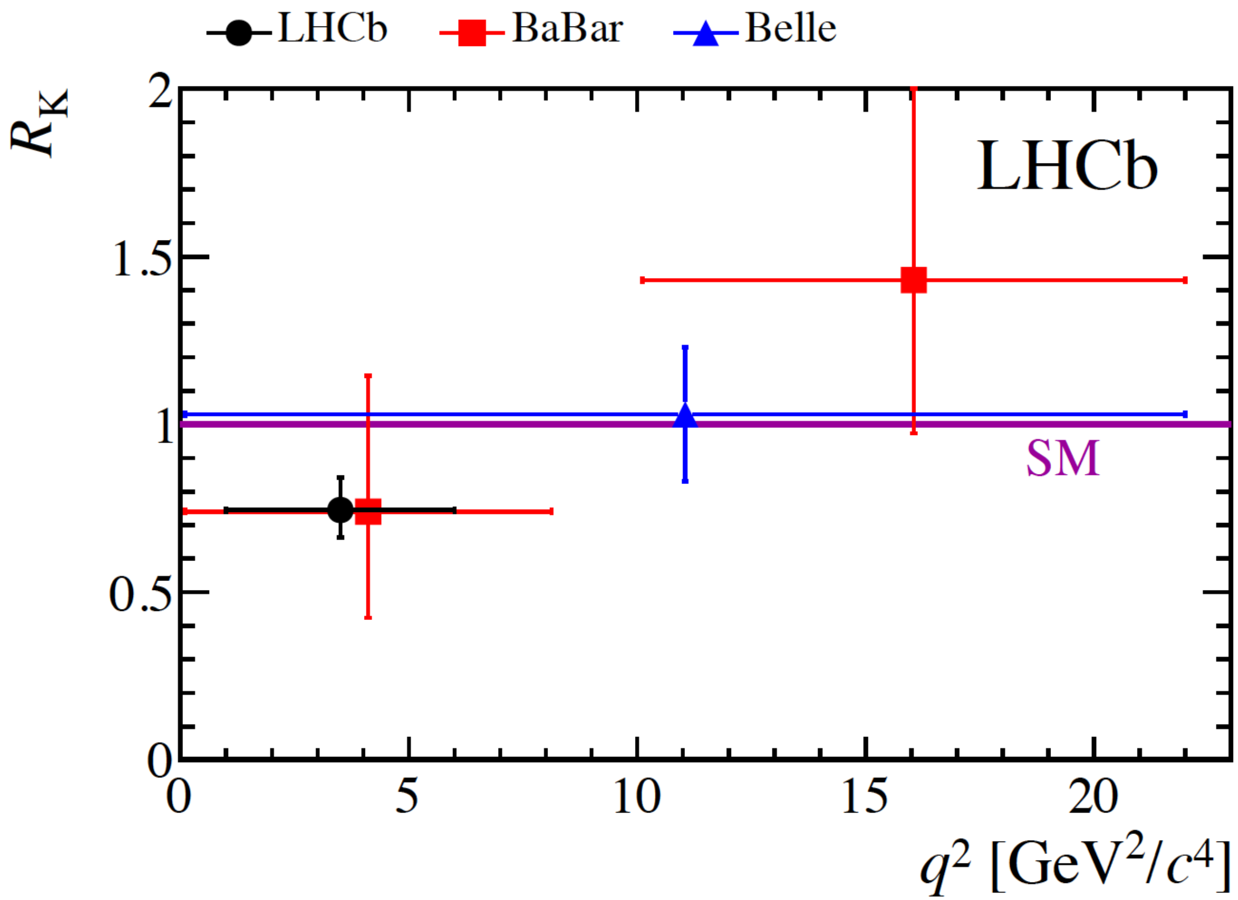
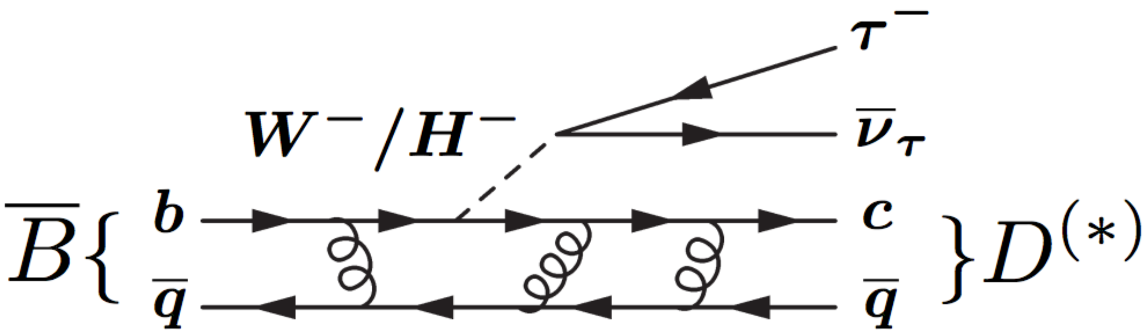


- **Compatible with Standard Model at 2.6** σ
- Measurements in the other bins were challenging (not enough events available)
- More data coming with run2 (and maybe some improvements in the analysis)
- Theoretical uncertainty ~10^{-3}

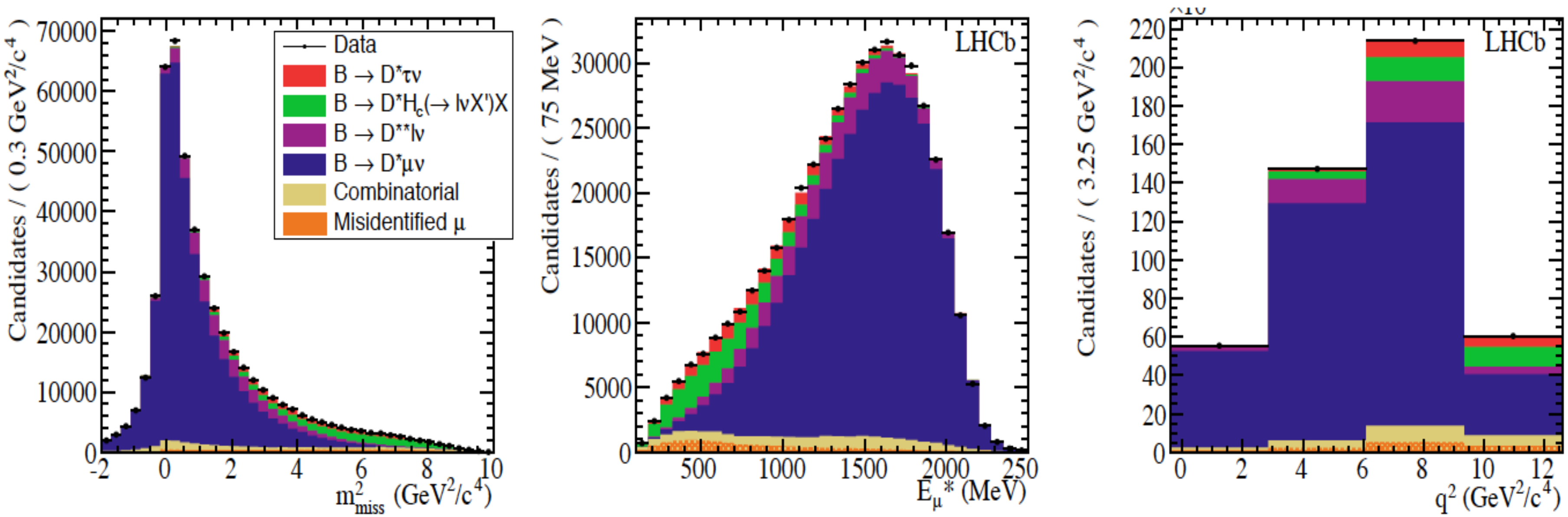
$$R_{D*} = \frac{\Gamma(\overline{B}^0 \to D^{*+}\tau^- \overline{\nu_\tau})}{\Gamma(\overline{B}^0 \to D^{*+}\mu^- \overline{\nu_\mu})}$$

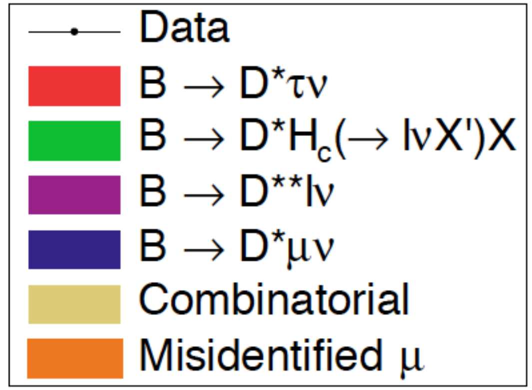
- In the Standard Model (lepton flavor universality), the mass of the lepton is the only difference between the two decays
- Theoretical uncertainty ~2% for $D*$ mode
- Sensitive to charged Higgs or non minimal flavor violating couplings favoring the tau



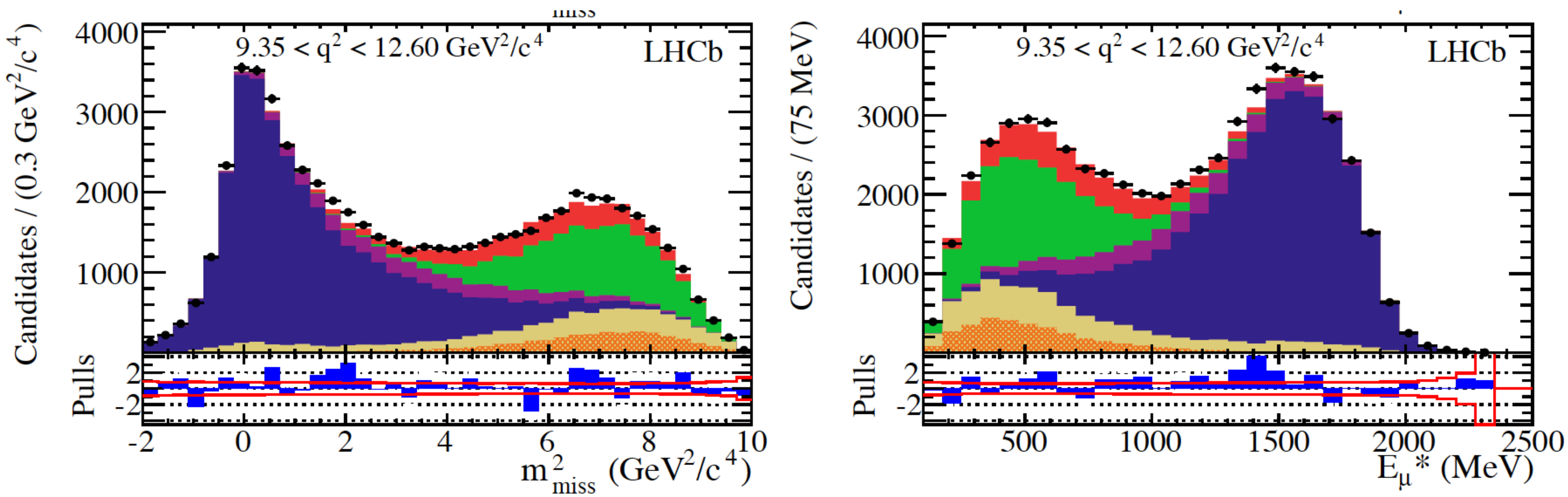
R_{D^*} : ANALYSIS STRATEGY PRL 115, 111803 (2015)

- Analysis performed on the whole run1 dataset: 3 fb^{-1}
- Neutrinos imply no narrow peak to fit in any distribution
- Use discriminating variables calculated in the B rest frame
  - the missing mass squared: $m^2_{\text{miss}} = (p^\mu_B - p^\mu_D - p^\mu_\mu)^2$
  - the muon energy: $E_\mu{}^*$
  - the squared four momentum transfer to the di-lepton system: q^2





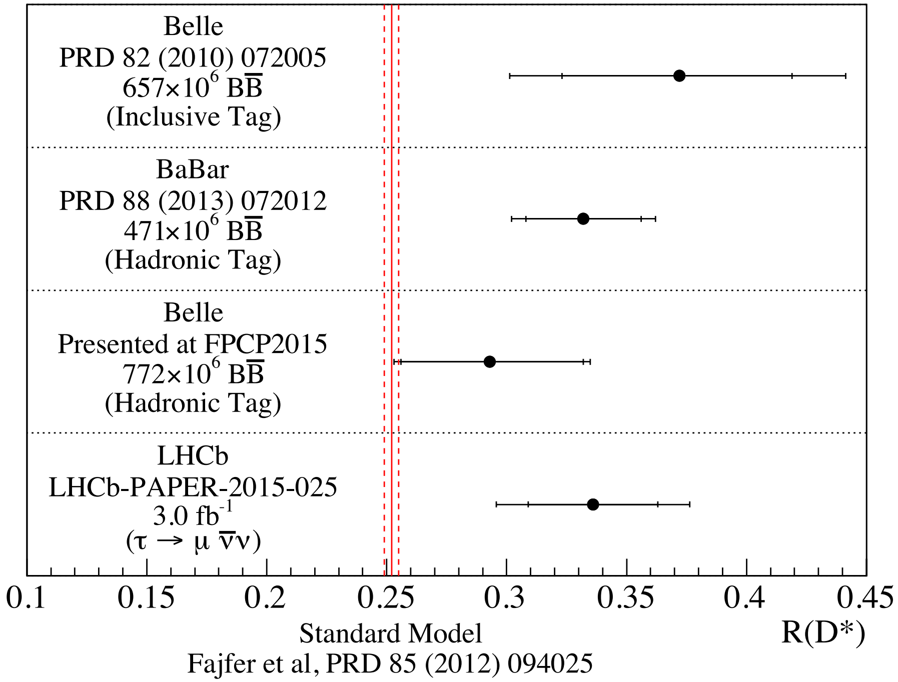
Zooming into the highest q^2 bin

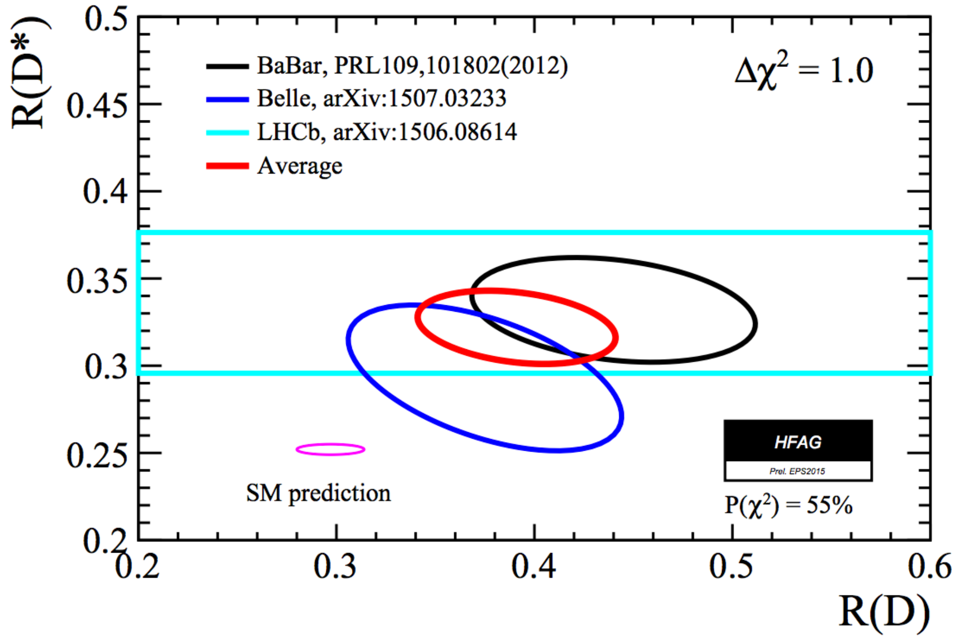


R_{D^*} : RESULTS

PRL 115, 111803 (2015)

- ***R(D*) = 0.336 ± 0.027 (stat) ± 0.030 (syst)***
- First measurement at an hadron collider
- **2.1σ larger than Standard Model expectation**
- Reduction of systematic error expected with more data coming





LFV IN B DECAYS: EXISTING LIMITS

$$\mathcal{B}(B^+ \to K^+ e^\pm \mu^\mp) < 9,1 \times 10^{-8}$$

$$\mathcal{B}(B^+ \to K^+ e^\pm \tau^\mp) < 3,0 \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^+ \tau^\pm \mu^\mp) < 4,8 \times 10^{-5}$$

$$\mathcal{B}(B^+ \to K^*(892)^+ e^\pm \mu^\mp) < 1,4 \times 10^{-6}$$

$$\mathcal{B}(B \to K^*(892)^0 e^\pm \mu^\mp) < 5,8 \times 10^{-7}$$

$$\mathcal{B}(B \to K e^\pm \mu^\mp) < 2,7 \times 10^{-7}$$

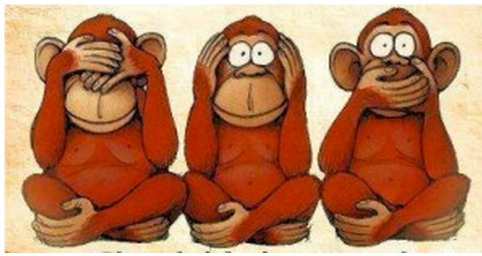
LFV IN B DECAYS AT LHCb: PLANS

* New lepton universality tests are being performed: **R_{K^*}, R_ϕ, R_Λ, R_D ...**

* **R_K** measurement could improve: with run2 data, and maybe with a new strategy

* Direct searches for charged lepton flavor violating decays under investigation:

- $B_{(s)} \to \tau\mu$, $B_{(s)} \to e\mu$
- $B^+ \to K^+ \tau\mu$, $B^0 \to K^{*0} \tau\mu$, $B^+ \to K^+ e\mu$, $B^0 \to K^{*0} e\mu$, $B_s \to \phi\tau\mu$, $B_s \to \phi e\mu$, ...
- each one might need a dedicated strategy
- some of these analysis can already be performed on run1 data
- an improvement of one order of magnitude on the existing limits could be possible (but since the analysis strategies are not yet finalized, it is hard to provide an estimate)

It is this:  *rather than this:* 

OTHER SUGGESTIONS?