# Test of lepton universality with $B^0 \rightarrow K^{*0}\, l^+ l^-$ decays

Alison Tully
Ana Maria Slivar
Birgit Stapf
Daniel Aguilar
Dario Ramirez
Dener Lemos
Erison Rocha
Federico Lamagna

Gonzalo Orellana
Indira Vergara
Marco Torres
Moisés León
Rafael Nuñez
Rafael Palacio
Rolando Calderón
Rosa Sandá Seoane

Introduction

- EW couplings of **e/μ/τ** to gauge bosons are independent of their flavour.
  - Lepton flavour universality
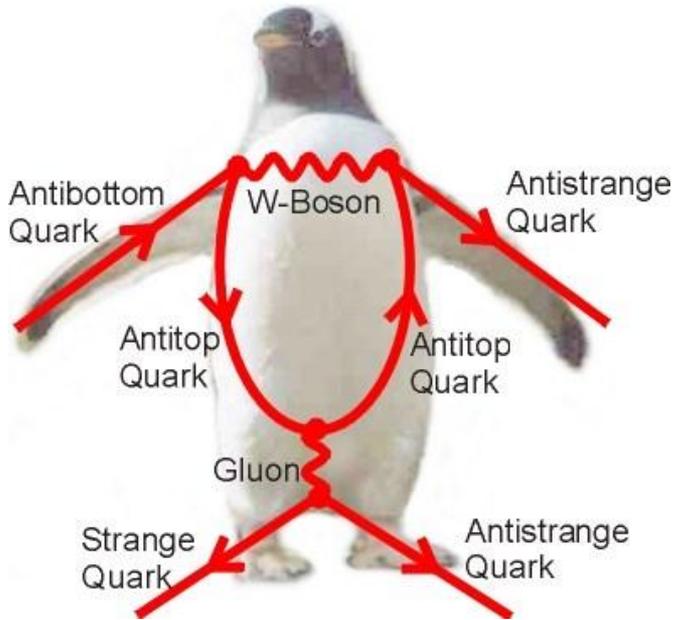- b→s decays are heavily suppressed in the SM
  - New physics easier to see
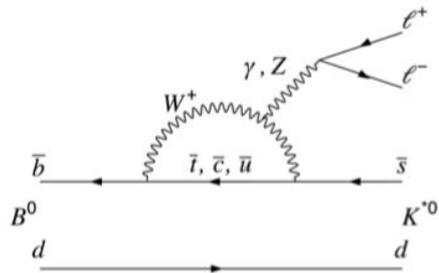
Penguin diagram
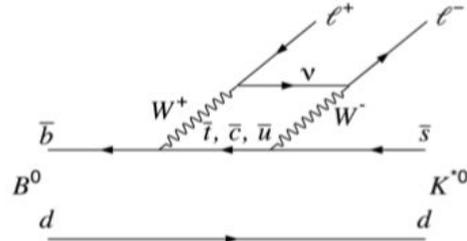
Box diagram

$$R_{K^{*0}} = \mathcal{B}(B^0 \rightarrow K^{*0}\ \mu^+\ \mu^-)/\mathcal{B}(B^0 \rightarrow K^{*0}\ e^+\ e^-) \quad \sim 1\ (SM)$$

Penguin diagram?

Antibottom Quark — W-Boson — Antistrange Quark

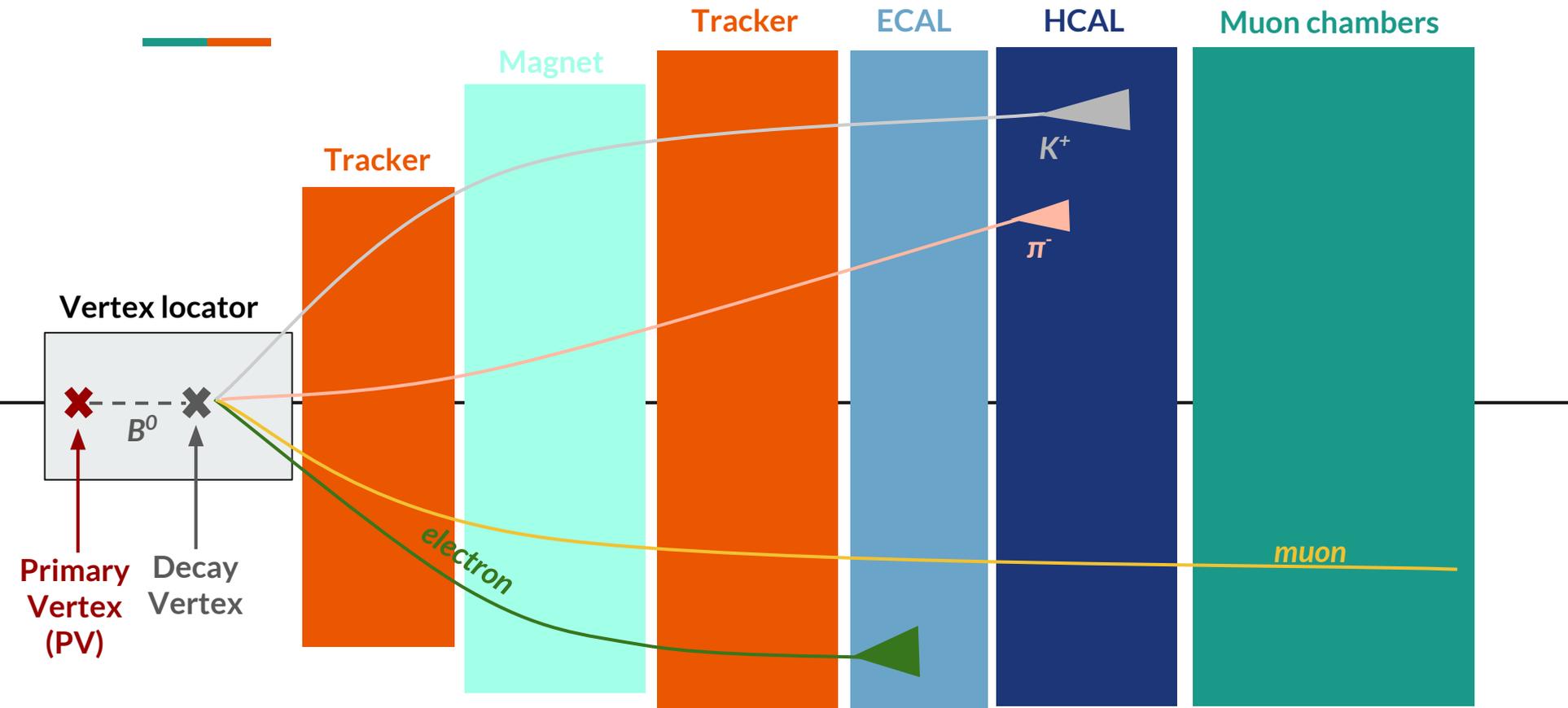Antitop Quark — Antitop Quark

Gluon

Strange Quark — Antistrange Quark

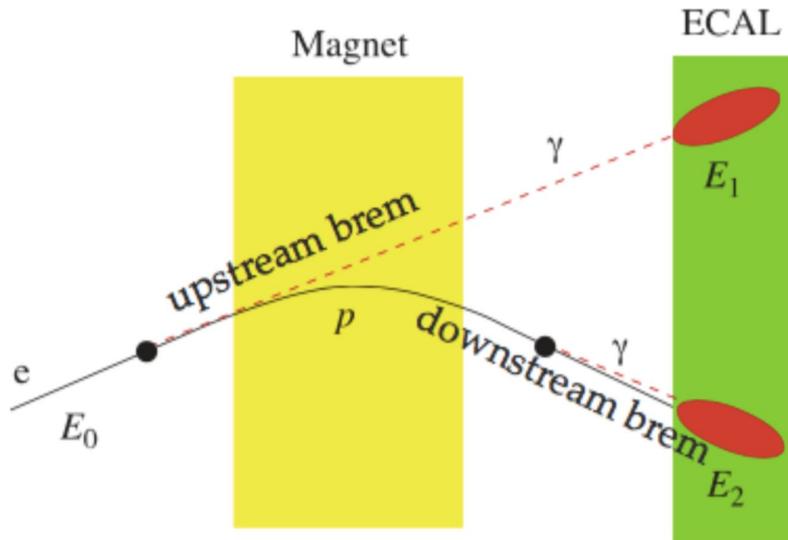# Measurement strategy

- In order to reduce systematic uncertainties, measure the double ratio:

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \Big/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$

- Easier to compare electrons to electrons, muons to muons

- Look at the following decay chain:
  - $B^0 \to K^{*0} l^+l^- \to K^+ \pi^- l^+l^-$
    - Machine learning and simple cuts to suppress backgrounds
    - Remaining background level small
- Measure R(K^{*0}) in two bins of m(l^+l^-) =q^2
- Using 3 fb^{-1} pp-collision data at CoM energies of 7 and 8 TeV collected with LHCb

LHCb detector

Tracker **ECAL** **HCAL** **Muon chambers**

Magnet

Tracker

K^+

π^-

Vertex locator

B^0

Primary Vertex (PV)

Decay Vertex
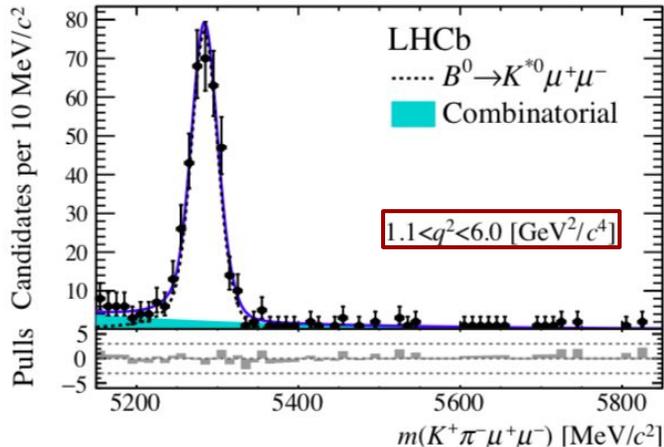
electron

muon

Challenges

- Electrons emit large amounts of **bremsstrahlung**
- Hard to associate photons to electron if emitted before magnet
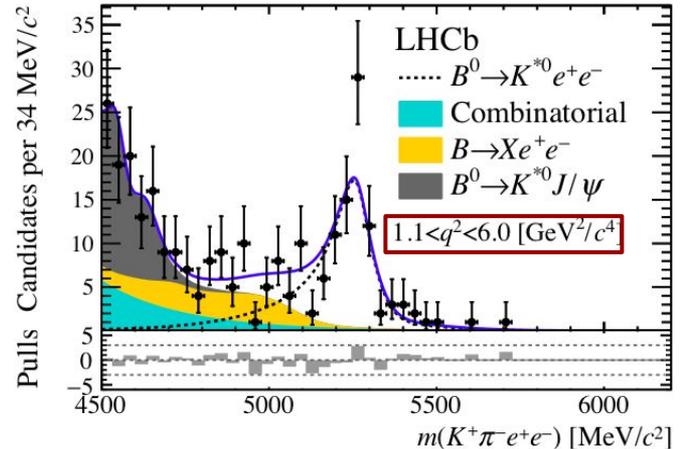- **Mass resolution** of electron **modes much worse**

Mass Fits

- Maximum likelihood fit to mass distributions to determine number of signal events
- Muons easy to measure precisely → clear narrow peak!
- Wider mass window for electrons due to worse resolution
  - Larger background contributions
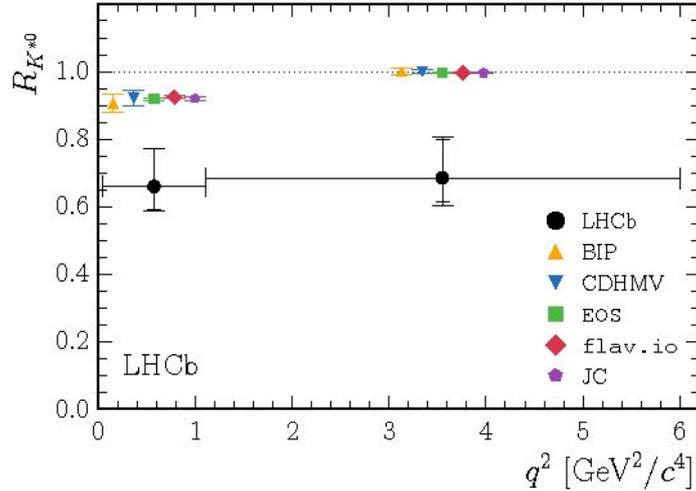
Muons

Electrons

Cross checks and systematics

- Test experimental method by measuring

$$r_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+ \mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+ e^-))} = 1.043 \pm 0.006 \pm 0.045$$

- Compatible with 1 → **differences between electrons and muons well modelled**

- Corrections are applied to simulation to make it look more like data
  - **Largest source of systematic uncertainty**
  - If no corrections are made, the result changes by <5%

Results

	low-q^2	central-q^2
$R_{K^{*0}}$	$0.66 \,^{+\,0.11}_{-\,0.07} \pm 0.03$	$0.69 \,^{+\,0.11}_{-\,0.07} \pm 0.05$
95.4% CL	$[0.52, 0.89]$	$[0.53, 0.94]$
99.7% CL	$[0.45, 1.04]$	$[0.46, 1.10]$

2.1-2.5 σ from SM!

Comparison with SM theoretical predictions
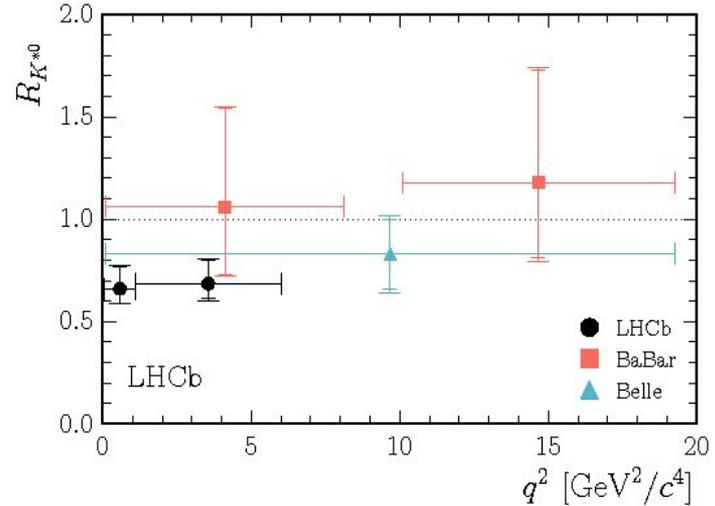
Comparison with other experiments

Other LFU tests

- R(K*) not the only LFU test
- τ/µ ratios also showing discrepancies with SM

2.5 σ from SM

3.8 σ from SM
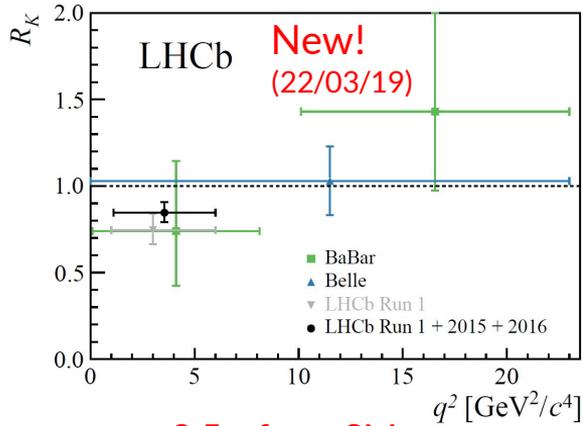
1.8 σ from SM

BSM Physics

Among the hottest **New Physics proposals**:
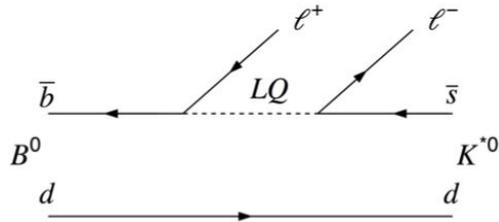
Leptoquarks:
Simultaneously couples to lepton and quark
Scalar or vector
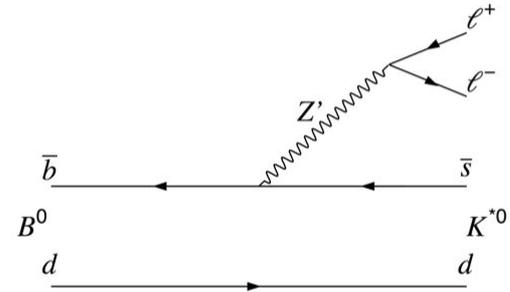
Z prime:
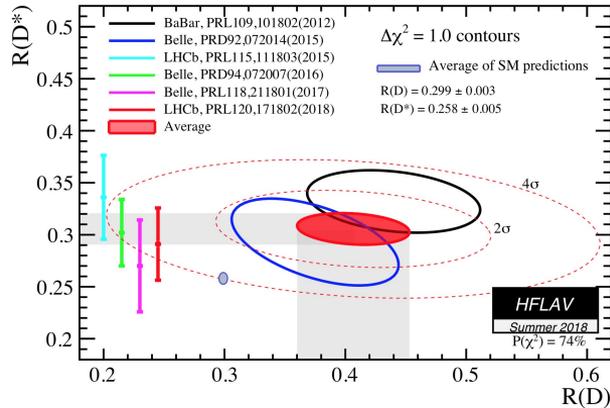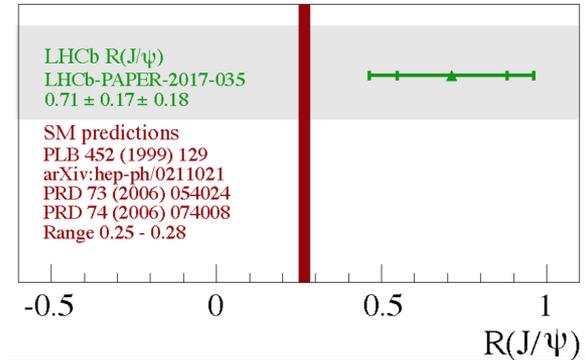Massive vector boson (broken U(1))

Can fit B anomalies
Flavor constrains couplings and masses!

Conclusions

- Most precise measurement of R(K*) to date

$$R_{K^{*0}} = \begin{cases} 0.66 \,{+}\,{0.11 \atop -}\,{} {0.07} \,(\text{stat}) \pm 0.03 \,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1 \ \text{GeV}^2/c^4 \\ 0.69 \,{+}\,{0.11 \atop -}\,{} {0.07} \,(\text{stat}) \pm 0.05 \,(\text{syst}) & \text{for } 1.1 \quad < q^2 < 6.0 \ \text{GeV}^2/c^4 \end{cases}$$

- Intriguing deviation from LFU → ~3σ combined!
- Possible indication of new physics
  - Leptoquarks, Z prime?
- Follow up measurement with run 2 data hotly anticipated!
  - ~ 5 times more data!
  - More data allows even more precise test

Conclusions

We need more data!

Thank You
Gracias
Obrigado
Danke

Backup

Event selection

- B0 candidate from SFOS lepton pair (ee or mm) and OS pair of K and pi
  - Require m(Kpi) within 100 MeV of the known K*0 mass
- Cut on pT (K, pi) > 250 MeV, pT(mu) > 800 MeV and pT(el) > 500 MeV
- Vertex quality requirements & reconstructed K*0 and lepton pair from same vertex
- Displaced vertex from the B0 consistent with its direction of flight
- Three trigger categories for ee events:
  - L0E: electron from B0 decay satisfies hardware trigger
  - L0H: one hadron from K*0 decay satisfies hardware trigger
  - L0I: triggered by event activity not from signal process
- For the resonant decay require lepton pair within mass window around J/Psi mass
  - 100 MeV for mumu events
  - Not possible for ee events due to large tails from bremsstrahlung
- Neural network used to separate signal and combinatorial background
  - Inputs: minimum and maximum pTs of the reconstructed particles, vertex quality, angles between B0, K+pi- and lepon pair, quality of kinematic fit

Backgrounds

Well understood backgrounds

- $B^0 \to K^{*0} V (\to l^+ l^-)$ decays, where V is a **ρ**, **ω** or **φ** meson
  - residual effect very small and safely rejected
- Misreconstructed $B^0 \to K^{*0} J/\psi (\to \mu^+ \mu^-)$ and $B^0 \to K^{*0} \psi(2S) (\to \mu^+ \mu^-)$ decays
  - invariant mass required to be outside of a 60 MeV interval around the known J/**ψ** or the **ψ**(2S) masses
- Nonpeaking background from the $B^0 \to D^- l^+ \mathbf{v}$ decay, with $D^- \to K^{*0} l^- \mathbf{v}$,
  - suppressed by requiring $|\cos \theta_l| < 0.8$
- $B^+ \to K^+ l^+ l^-$ decays can pass the selection and populate the upper mass sideband region
  - vetoed by requiring the invariant mass of the $K^+ l^+ l^-$ combination to be less than 5100 MeV
- Combinatorial background
  - accidental association of particles produced by different $\bar{b}$ and $\bar{c}$ hadron decays

Tuning of the simulation

MC simulations made using PYTHIA for events, EVTGEN for decays, and GEANT4 for detector.

Three steps for correcting the simulations:

1. Differences between simulation and data in PID
2. Adjust for the charged-track multiplicity in the event.
3. Correct the trigger response (tag and probe)
4. Account differences for using
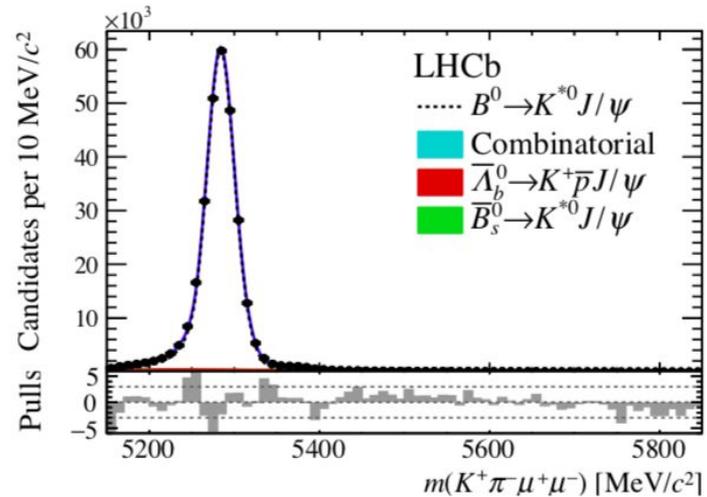
$$B^0 \to K^{*0} J(\to l^+ l^-)$$

Efficiencies

$$\frac{\varepsilon_{\ell^+\ell^-}}{\varepsilon_{J/\psi(\ell^+\ell^-)}} = \frac{\mathcal{N}_{J/\psi(\ell^+\ell^-)}}{\mathcal{N}_{\ell^+\ell^-}} \frac{\mathcal{B}_{\ell^+\ell^-}}{\mathcal{B}_{J/\psi(\ell^+\ell^-)}}$$

$$\mathcal{B}_{\ell^+\ell^-} = \mathcal{B}(B^0 \to K^{*0}\ell^+\ell^-)$$

	$\varepsilon_{\ell^+\ell^-}/\varepsilon_{J/\psi(\ell^+\ell^-)}$	
	low- q^2	central- q^2
$\mu^+\mu^-$	0.679 ± 0.009	0.584 ± 0.006
e^+e^- (L0E)	0.539 ± 0.013	0.522 ± 0.010
e^+e^- (L0H)	2.252 ± 0.098	1.627 ± 0.066
e^+e^- (L0I)	0.789 ± 0.029	0.595 ± 0.020

J/psi mass fits
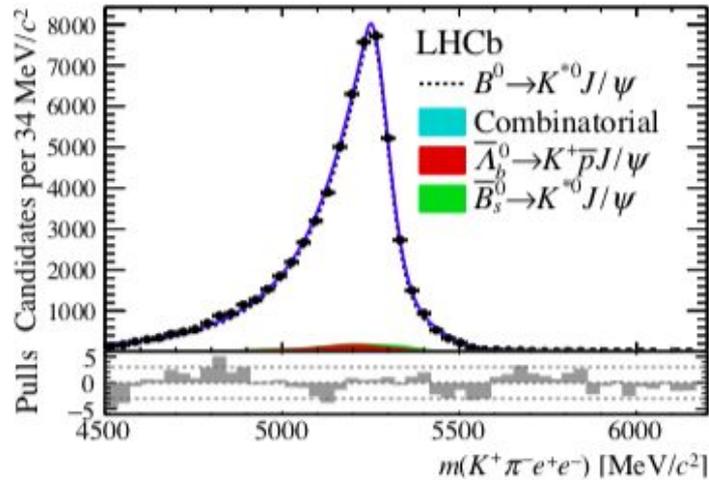
Total signal yields

	$B^0 \rightarrow K^{*0}\ell^+\ell^-$		$B^0 \rightarrow K^{*0}J/\psi(\rightarrow \ell^+\ell^-)$
	low-q^2	central-q^2	
$\mu^+\mu^-$	$285 \, ^{+ \, 18}_{- \, 18}$	$353 \, ^{+ \, 21}_{- \, 21}$	$274416 \, ^{+ \, 602}_{- \, 654}$
e^+e^- (L0E)	$55 \, ^{+ \, 9}_{- \, 8}$	$67 \, ^{+ \, 10}_{- \, 10}$	$43468 \, ^{+ \, 222}_{- \, 221}$
e^+e^- (L0H)	$13 \, ^{+ \, 5}_{- \, 5}$	$19 \, ^{+ \, 6}_{- \, 5}$	$3388 \, ^{+ \, 62}_{- \, 61}$
e^+e^- (L0I)	$21 \, ^{+ \, 5}_{- \, 4}$	$25 \, ^{+ \, 7}_{- \, 6}$	$11505 \, ^{+ \, 115}_{- \, 114}$

Systematic Uncertainties

Many potential sources of systematic uncertainties are canceled because of double ratio R_{k*0}.

Largest systematics are:

✓ Corrections to simulation:
  - For all q²
✓ Residual background:
  - Only for central q²

Trigger category	$\Delta R_{K^{*0}}/R_{K^{*0}}$ [%] low-q^2 L0E	low-q^2 L0H	low-q^2 L0I	central-q^2 L0E	central-q^2 L0H	central-q^2 L0I
Corrections to simulation	2.5	4.8	3.9	2.2	4.2	3.4
Trigger	0.1	1.2	0.1	0.2	0.8	0.2
PID	0.2	0.4	0.3	0.2	1.0	0.5
Kinematic selection	2.1	2.1	2.1	2.1	2.1	2.1
Residual background	–	–	–	5.0	5.0	5.0
Mass fits	1.4	2.1	2.5	2.0	0.9	1.0
Bin migration	1.0	1.0	1.0	1.6	1.6	1.6
$r_{J/\psi}$ ratio	1.6	1.4	1.7	0.7	2.1	0.7
Total	4.0	6.1	5.5	6.4	7.5	6.7

Note: L0E => e⁻ from B⁰ decay satisfying the hardware e⁻ trg
         L0H => hadron from K*⁰ decay satisfying the hardware hadron trg
         L0I => candidates triggered not associated with ay of signal decay particles

Other anomalies

Branching fractions consistently too low for many rare processes

Large discrepancy in theoretically clean angular observable P5'

- [JHEP 02 (2016) 104](#)   [ATLAS-CONF-2017-023](#)
- [PRL 118 (2017)](#)   [arXiv:1710.02846](#)

[JHEP 06 (2014) 133](#)

[JHEP 10 (2016) 047](#)
[JHEP 04 (2017) 142](#)

[JHEP 06 (2015) 115](#)

[JHEP 09 (2015) 179](#)