Measurements of R_K and R_{K^*} at LHCb

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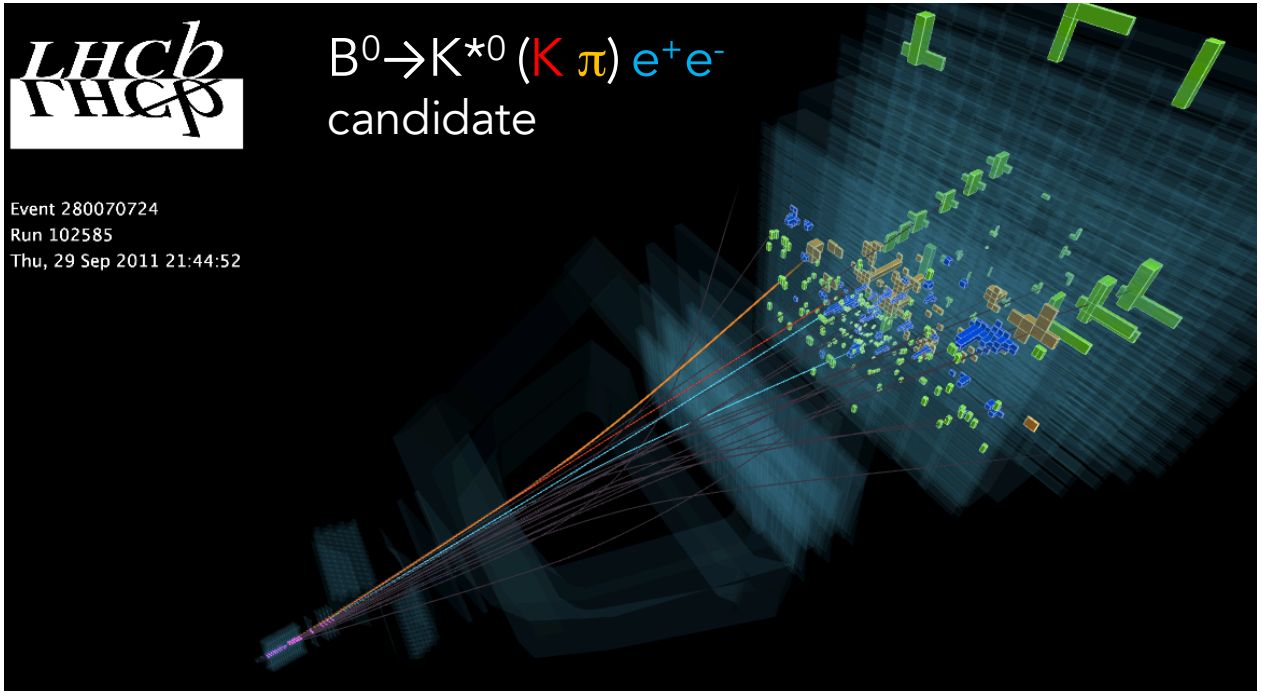
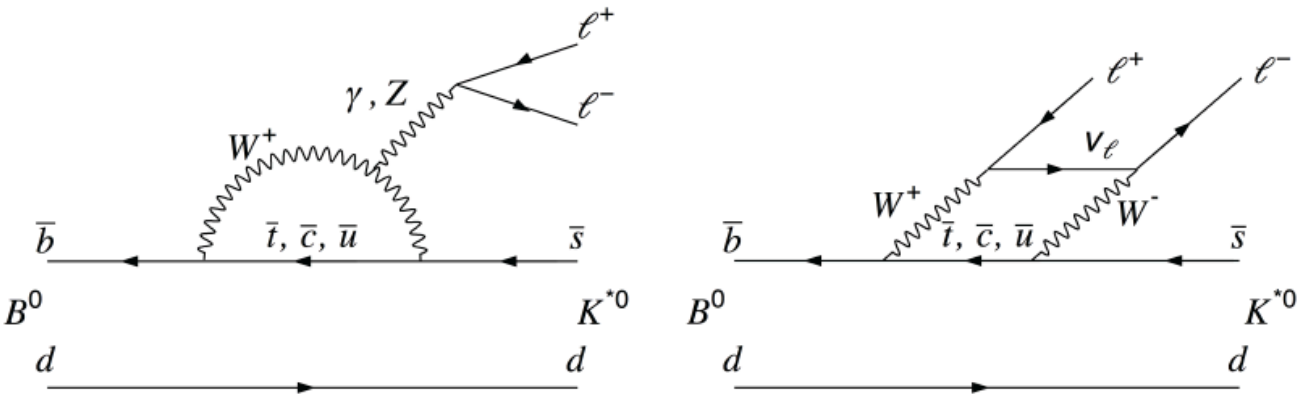
On behalf of the LHCb Collaboration



The R ratios family

In the SM :



ℓ=e, μ or τ

$$R_H = \frac{\int \frac{d\Gamma(B \to H\mu^+\mu^-)}{dq^2}\, dq^2}{\int \frac{d\Gamma(B \to He^+e^-)}{dq^2}\, dq^2}$$

q = M(ℓℓ)

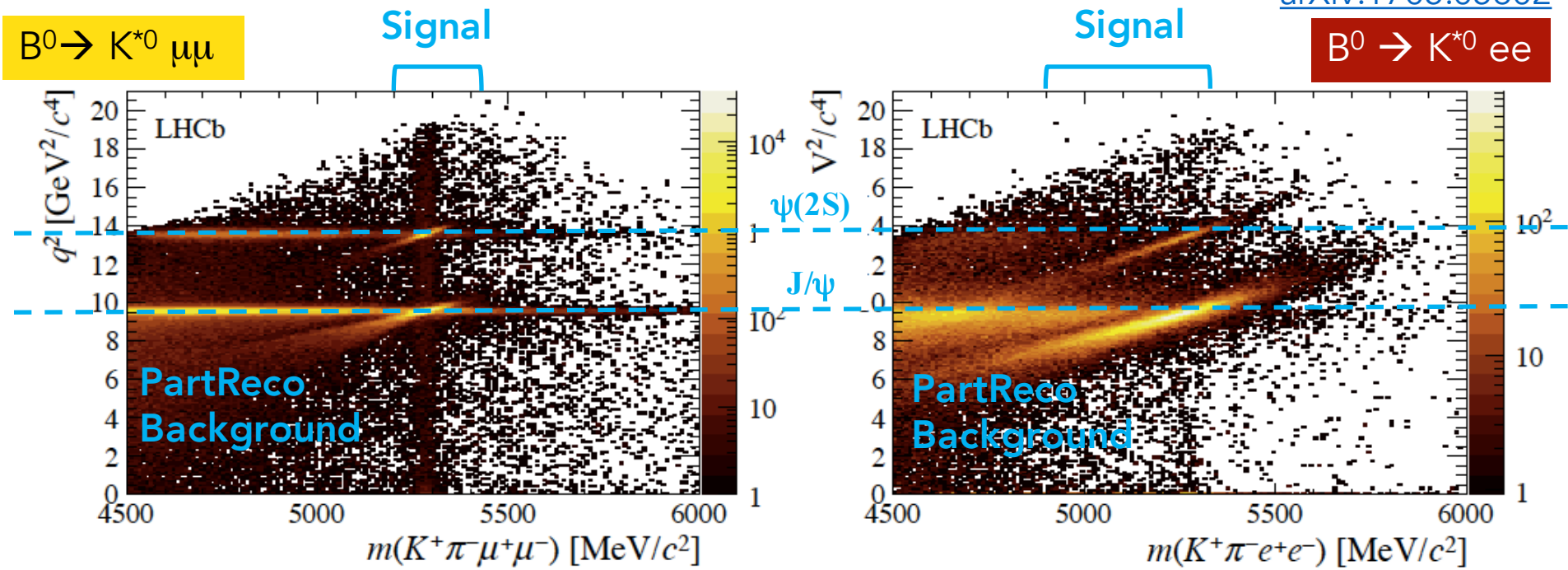
R_H =1 (at 10^{-3}) in the SM (neglecting lepton masses)

QED effects ~ % arXiv:1605.07633

R_K , R_{K^*} , R_ϕ …

Experimentally challenging at the LHC

arXiv:1705.05802



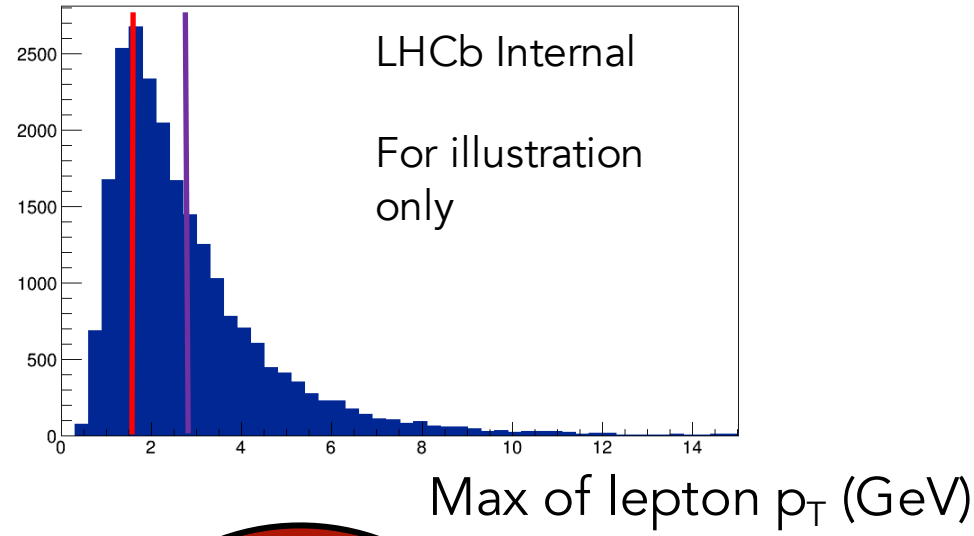
Electrons emit a large amount of bremsstrahlung → degraded momentum and mass resolutions → recovery procedure is in place but incomplete (calorimeter acceptance, E_T of the photon > 75 MeV ….)

⟹ the reconstructed B mass shifts towards lower values and events migrate in and out of the q2 bins

LHC : 15 MHz of visible crossing

LHCb : readout of the detector : 1 MHz

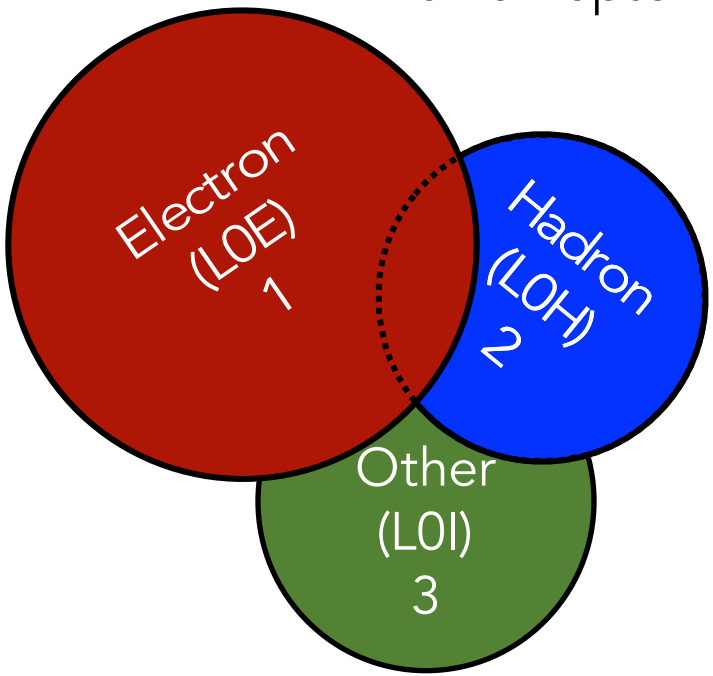
$K^* \ell\ell$ Generator level, $1.1<q^2<6$ GeV^2/c^4



⟹ hardware trigger :

L0 Muon p_T>1.5 - 1.8 GeV
L0 Electron E_T > 2.5 – 3.0 GeV
L0 Hadron E_T > 3.5 GeV

Electron channels :
three exclusive trigger categories



Muon channels :
one single muon trigger category

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

- Selection as similar as possible between μμ and ee for physics-related variables

Mitigating electron/muon differences

- The ee channels are treated separately for the various trigger categories (different mass shapes, different background levels, different efficiencies …)
- The efficiencies are determined using simulation, but tuned using data
- Blind analyses

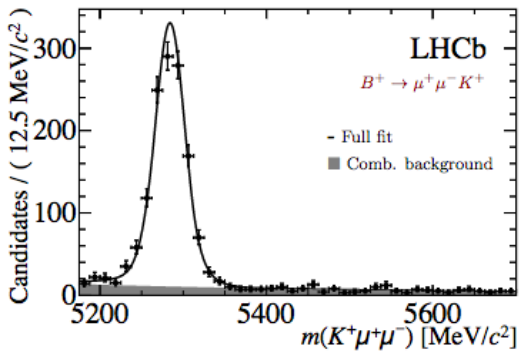
in 2014 : R(K)

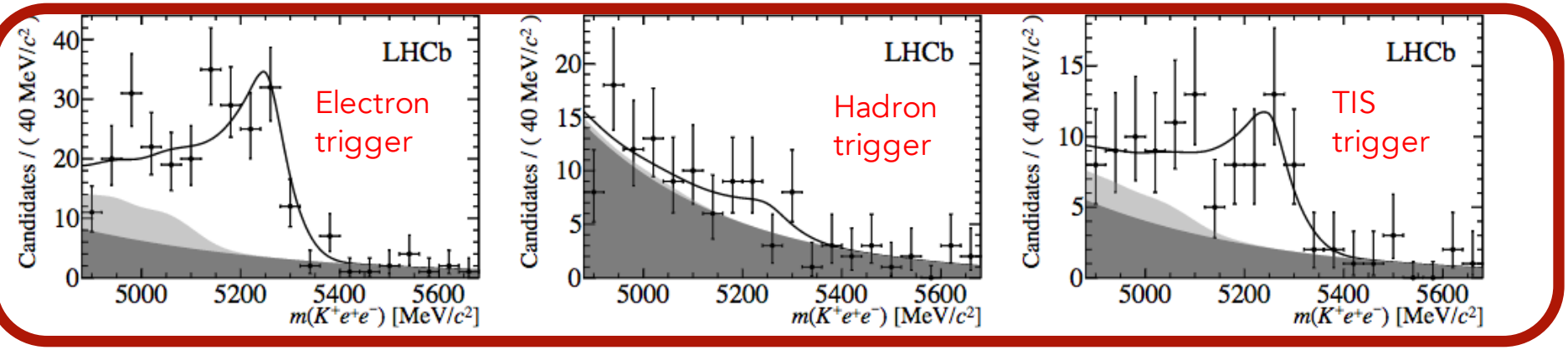
PRL 113 (2014) 151601

Run1 : 3 fb^{-1}

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

	$1<q^2<6$ GeV^2/c^4	J/ψ
μμ	1226 ± 41	667k
ee	254 ± 28	62k

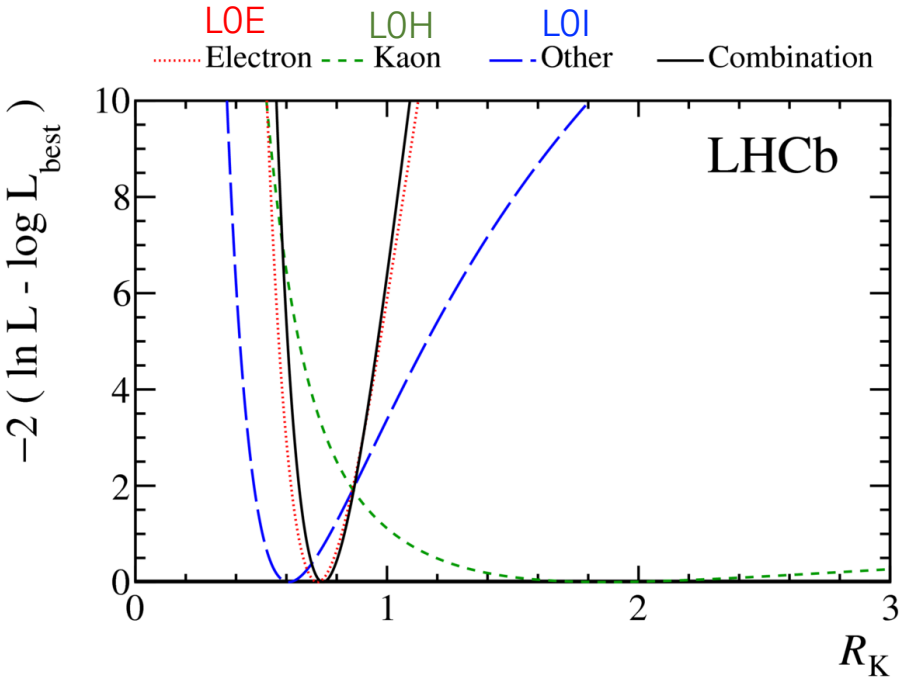


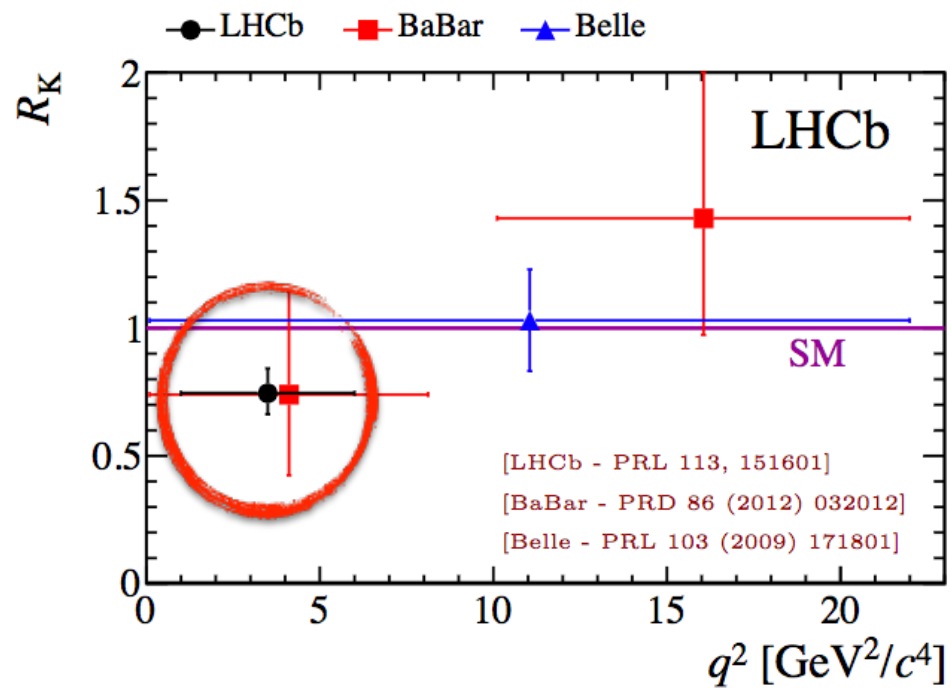


$1<q^2< 6\ \mathrm{GeV}^2/c^4$

$$R_K = 0.745^{+0.090}_{-0.074}(\mathrm{stat}) \pm 0.036(\mathrm{syst})$$

PRL 113 (2014) 151601





2.6 standard deviations from the SM prediction

Replace the K by a K^{*0}

Run1 : 3 fb^{-1}

arXiv:1705.05802

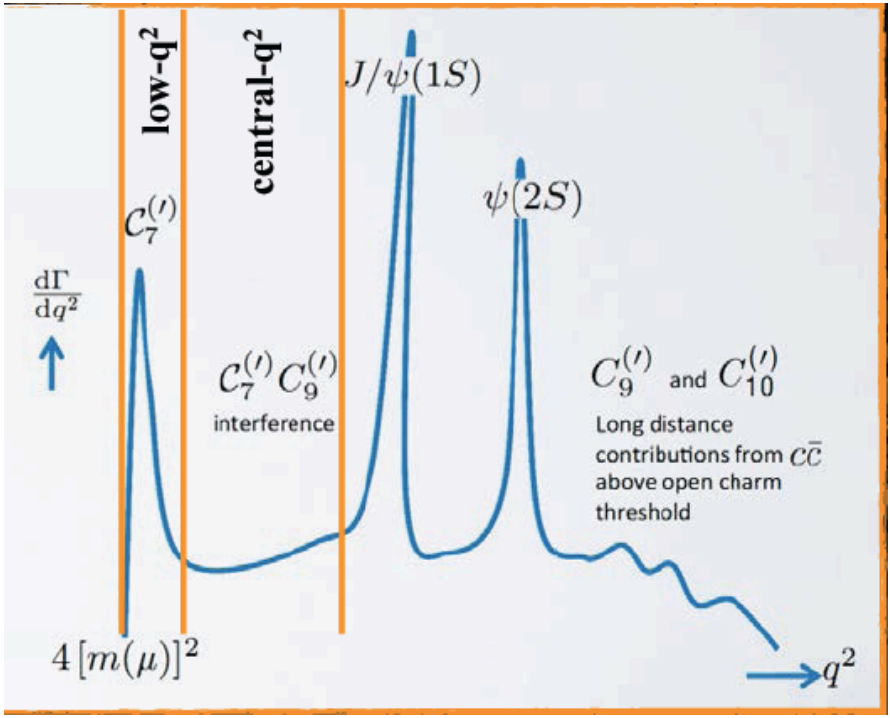
$$R_{K^{*0}} = \frac{\int \frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{dq^2}\, dq^2}{\int \frac{d\Gamma(B^0 \to K^{*0}e^+e^-)}{dq^2}\, dq^2}$$

K^{*0} : $M(K^+ \pi^-) = M(K(892)^0) \pm 100$ MeV

Two hadrons instead of one :
lower p_T, higher combinatorial background

Low-q^2 : [0.045-1.1] GeV^2/c^4
$M(\ell\ell)$: [212 – 1049] MeV/c^2

Central-q^2 : [1.1-6.0] GeV^2/c^4
$M(\ell\ell)$: [1049-2449] MeV/c^2



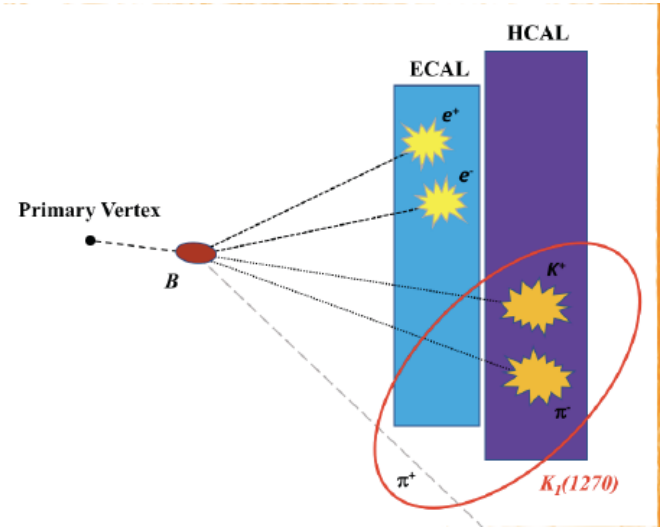
The ϕ resonance is fully included in the low-q^2 region

The J/ψ leakage is limited in the central-q^2 region

Analysis roadmap :

- Selection using MVA & kinematics properties of the event (ee)
- Data/simulation differences in Kπ ee mass reconstruction obtained from J/ψ(ee) Kπ
- Partially reconstructed background : simulation checked against data

Details in the backup slides

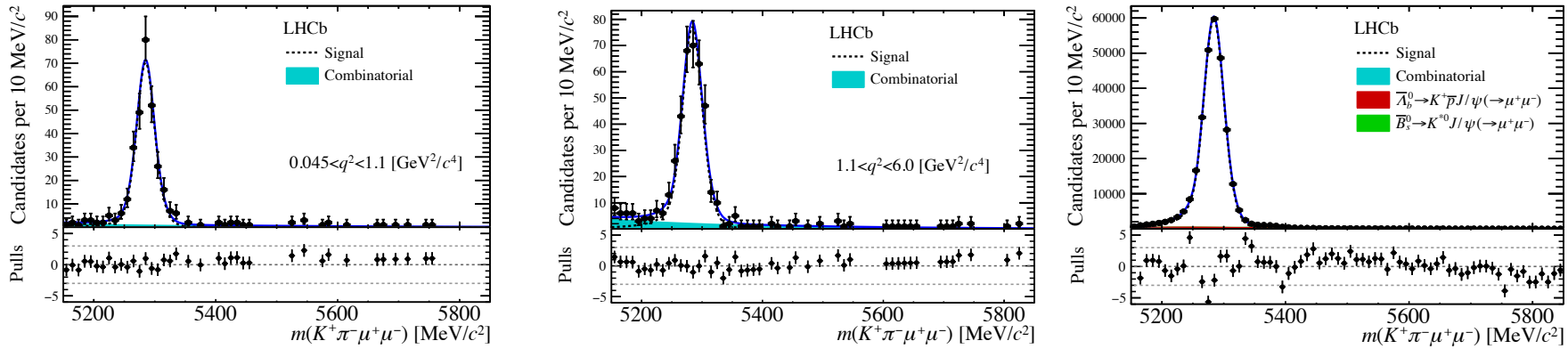


To compute the absolute scale of the efficiency in the ee and μμ channels : large set of corrections to the simulation, based on tag and probe technique

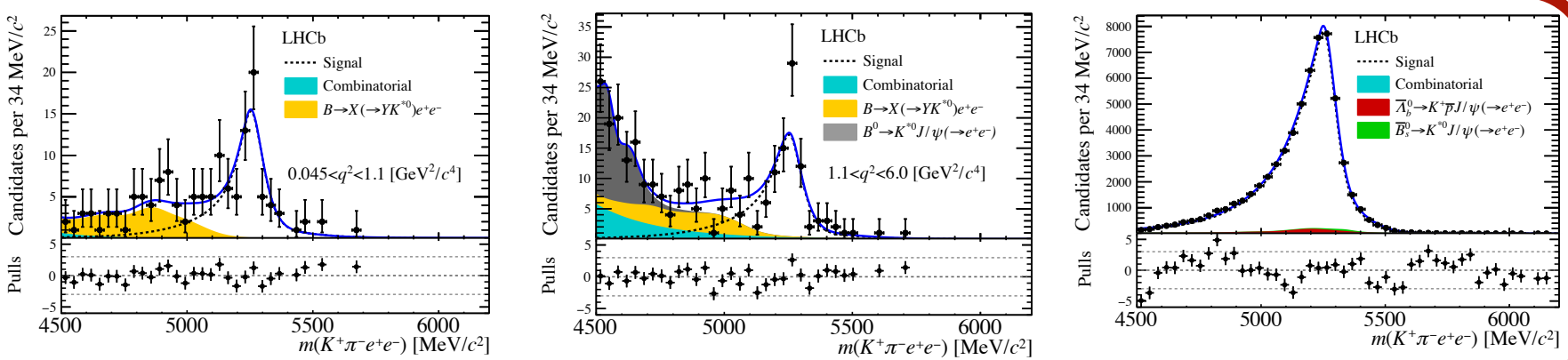
- Particle Identification
- Generator (event multiplicity, B^0 kinematics)
- Trigger
- Residual discrepancies in variables entering the MVA tool used to separate the signal from background.

Low-q^2 Central-q^2 J/ψ

$B^0 \to K^{*0}\mu\mu$



$B^0 \to K^{*0}ee$



Yields :

	Low-q^2	Central-q^2	J/ψ
μμ	285 ± 18	353 ± 21	274k
ee	89 ± 11	111 ± 14	58k

arXiv:1705.05802

Crosschecks :

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

~ independent of the decay kinematics and event multiplicity (non flatness in the systematics of $R_{K^{*0}}$)

Extremely stringent test, systematics due to corrections larger than those for $R_{K^{*0}}$

- BR($B^0 \to K^{*0}\ \mu\mu$) in good agreement with arxiv:1606.04731

- $$\mathcal{R}_{\psi(2S)} = \frac{\mathcal{B}(B^0 \to K^{*0}\psi(2S)(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))} \Big/ \frac{\mathcal{B}(B^0 \to K^{*0}\psi(2S)(\to e^+e^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))}$$

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

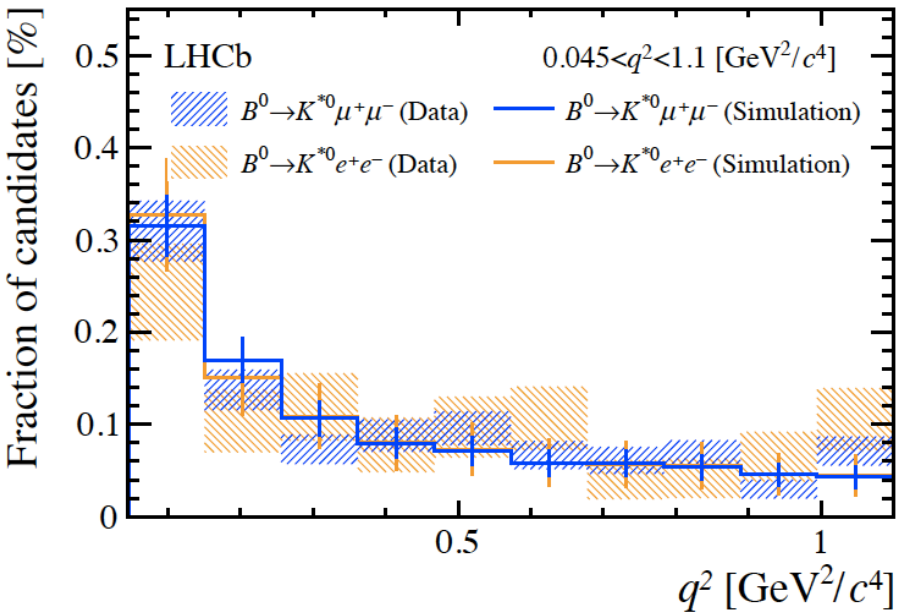
  compatible with expectations

- If corrections to simulation are not accounted for, the ratio of the efficiencies (and thus $R_{K^{*0}}$) changes by less than 5%

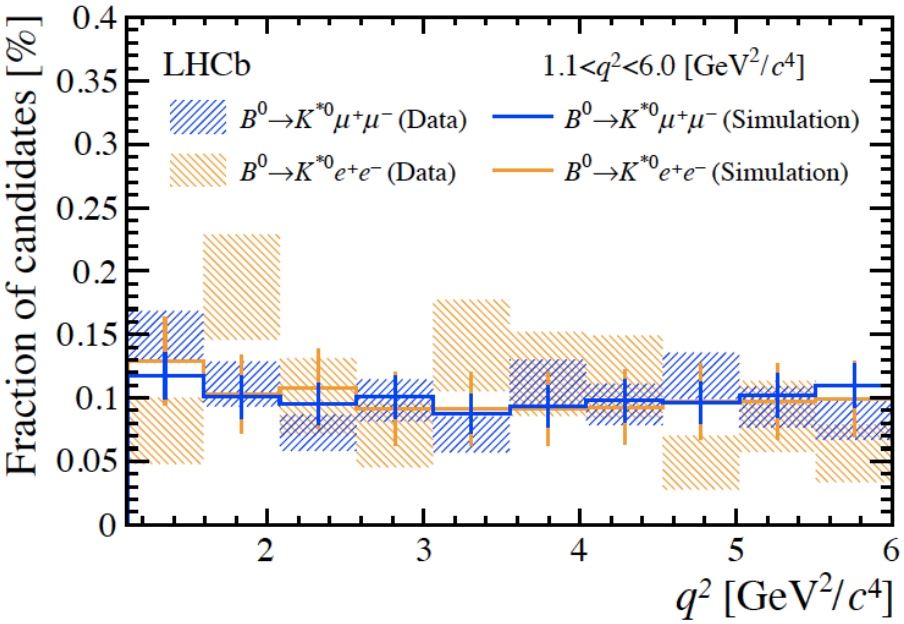
Other checks :

distributions obtained from background-subtracted data (sPlot NIM A555,356-369 (2005)) and compared to simulation

Low-q^2



Central-q^2



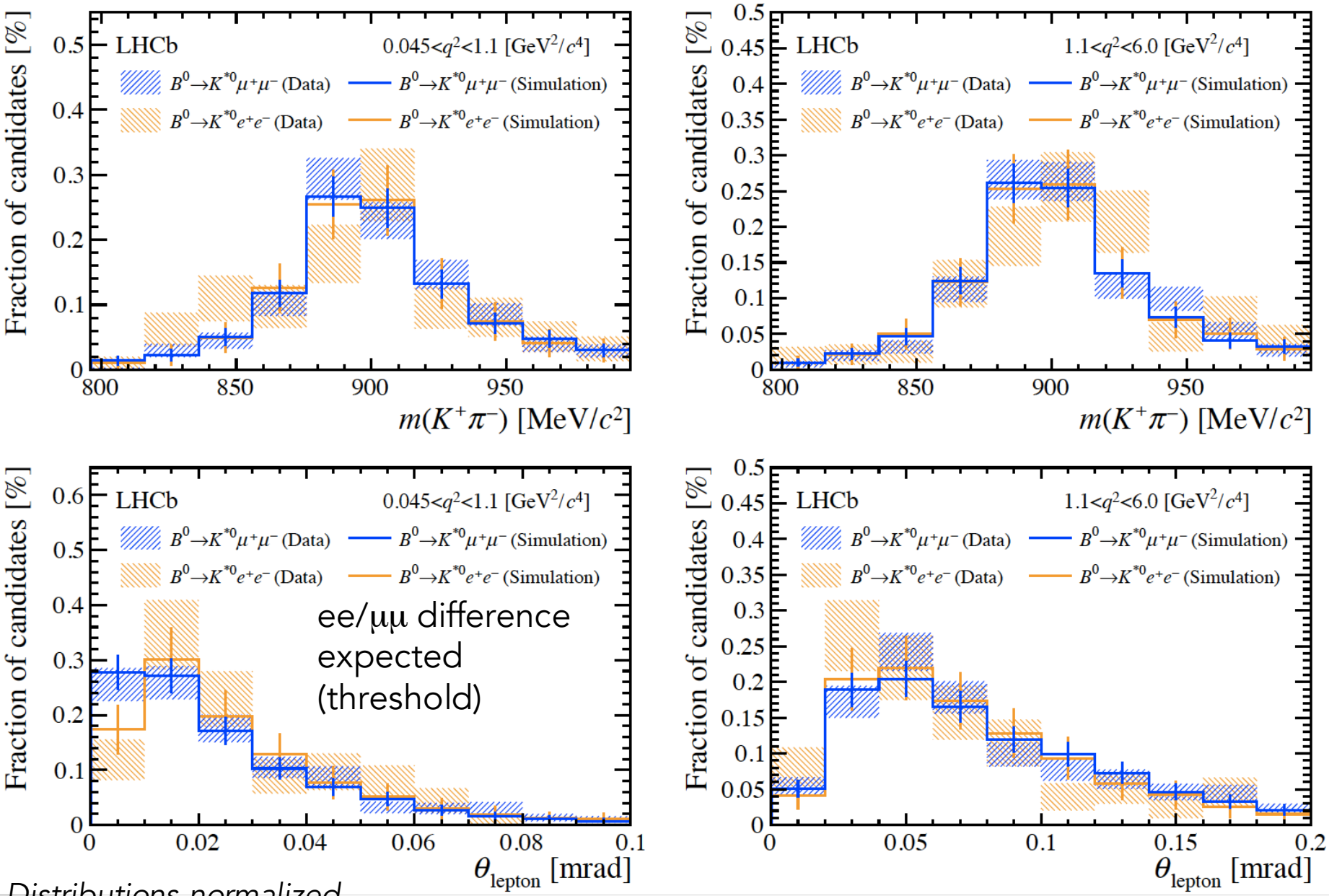
Good agreement between electrons and muons and data and simulation

Distributions normalized to the same area

arXiv:1705.05802

Low-q^2 Central-q^2

arXiv:1705.05802



Distributions normalized to the same area

Systematics uncertainties on $R_{K^{*0}}$:

arXiv:1705.05802

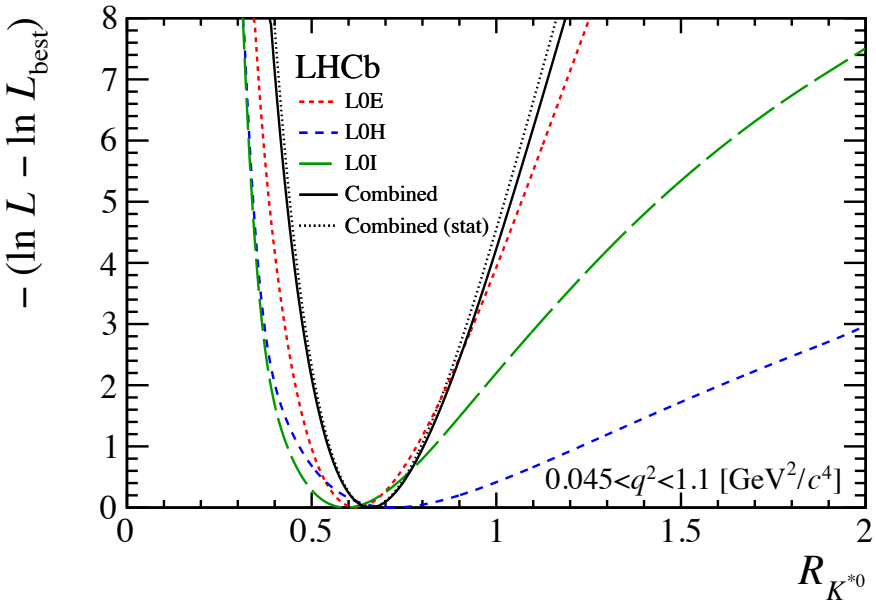
- Use of a double ratio : many experimental systematic effects cancel
- Statistically dominated (~ 15%)

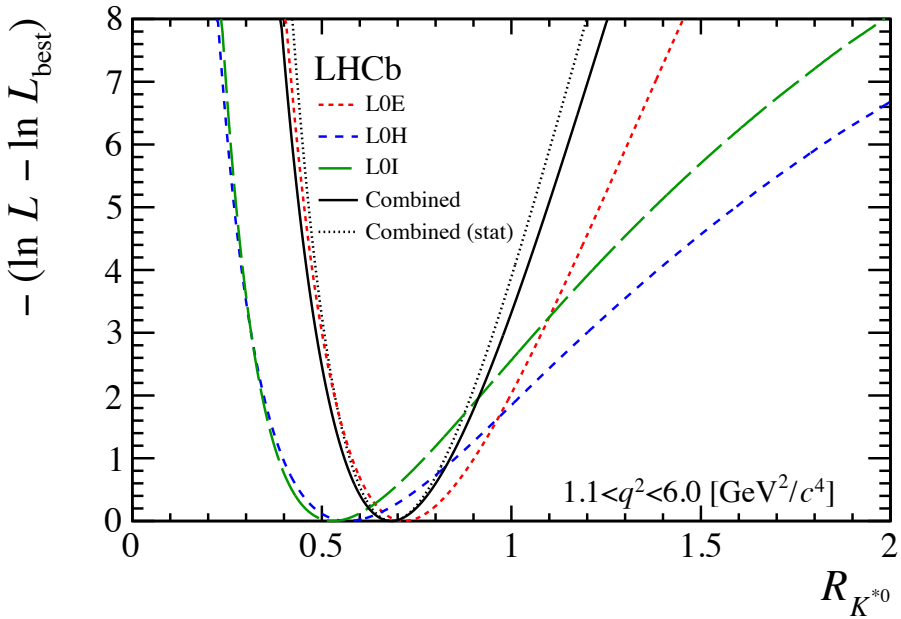
(table in %)

	low-q^2			central-q^2		
Trigger category	L0E	L0H	L0I	L0E	L0H	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
$r_{J/\psi}$ flatness	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

Brem tail description

Residual background contamination due to $B \to K^{*0} J/\psi(ee)$ events with a $K \leftrightarrow e$ or $\pi \leftrightarrow e$ swap



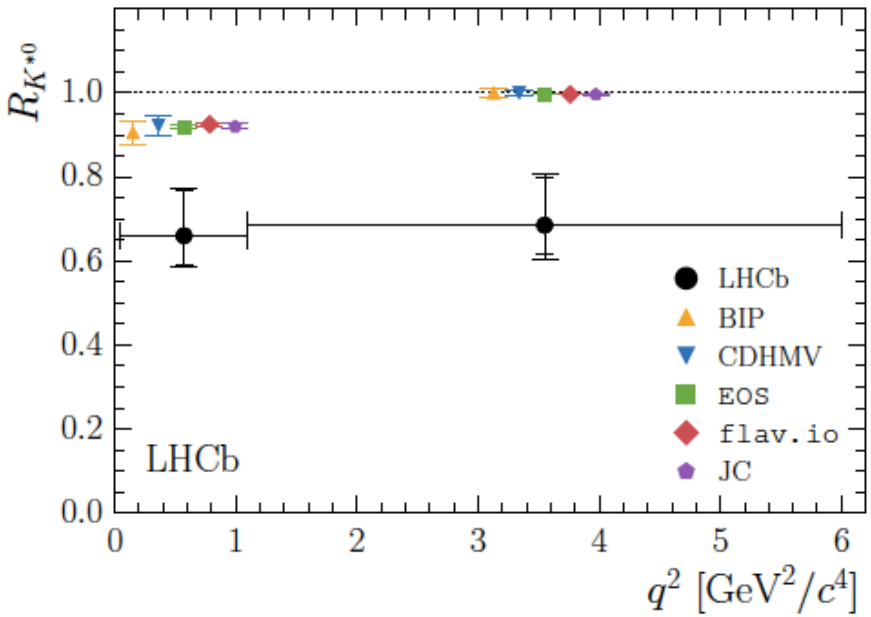


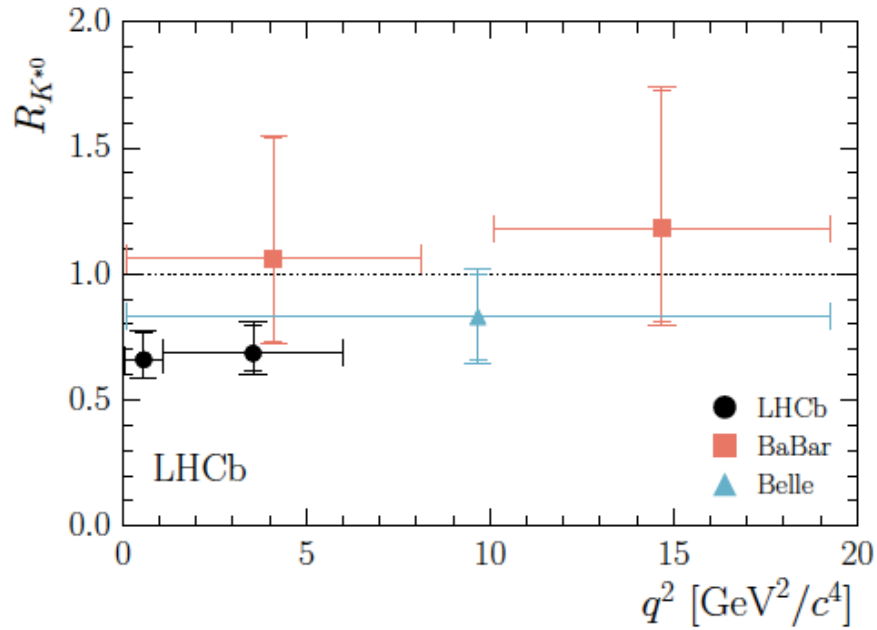
arXiv:1705.05802

	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	$[0.45, 1.04]$	$[0.46, 1.10]$

Good agreement between trigger categories

arXiv:1705.05802





- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

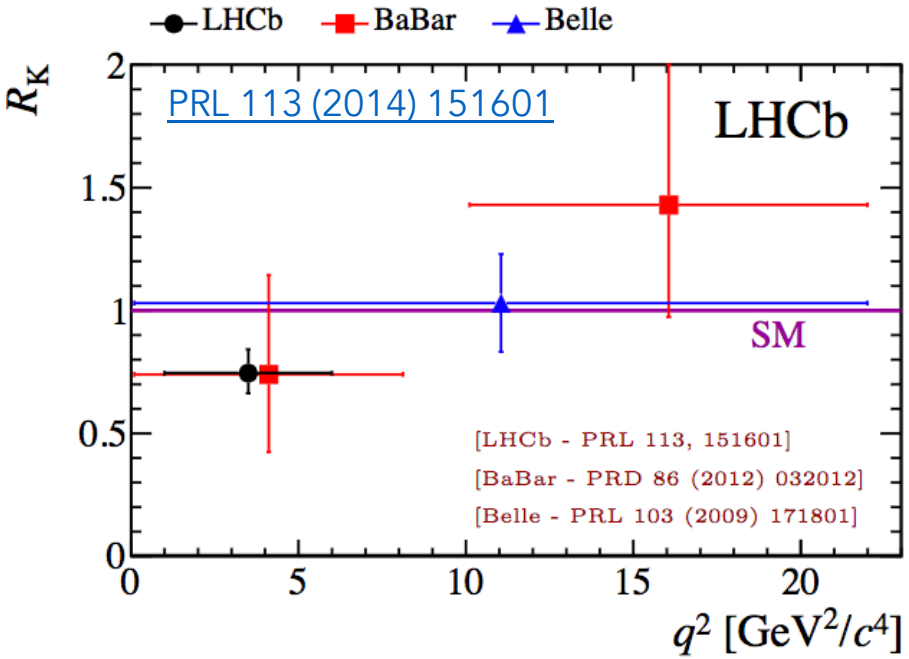
BIP	arXiv:1605.07633
CDHMV	arXiv:1510.04239, 1605.03156, 1701.08672
EOS	arXiv:1610.08761, https://eos.github.io
flav.io	arXiv:1503.05534, 1703.09189, flav-io/flavio
JC	arXiv:1412.3183

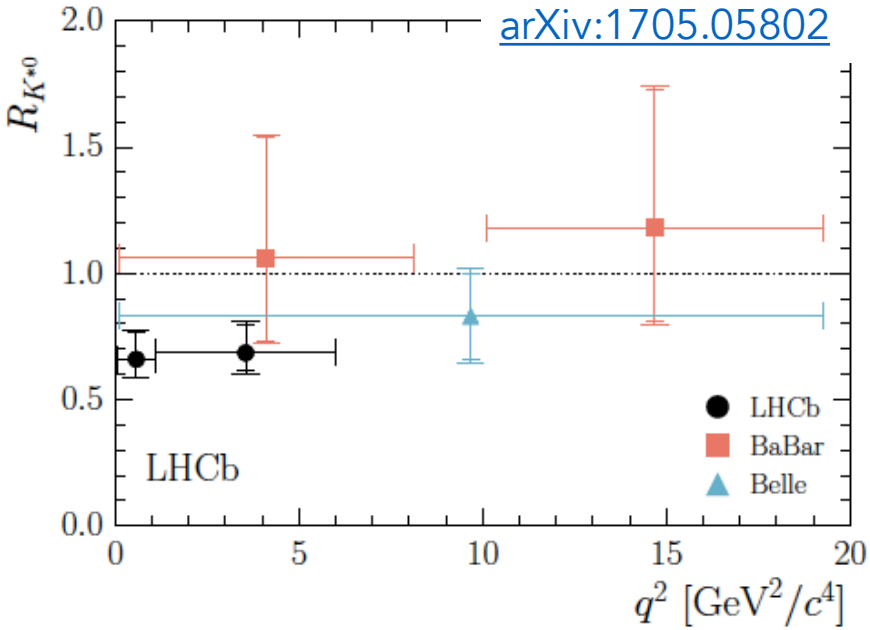
Compatibility with the SM expectation(s) : Low-q^2: 2.1 – 2.3 standard deviations

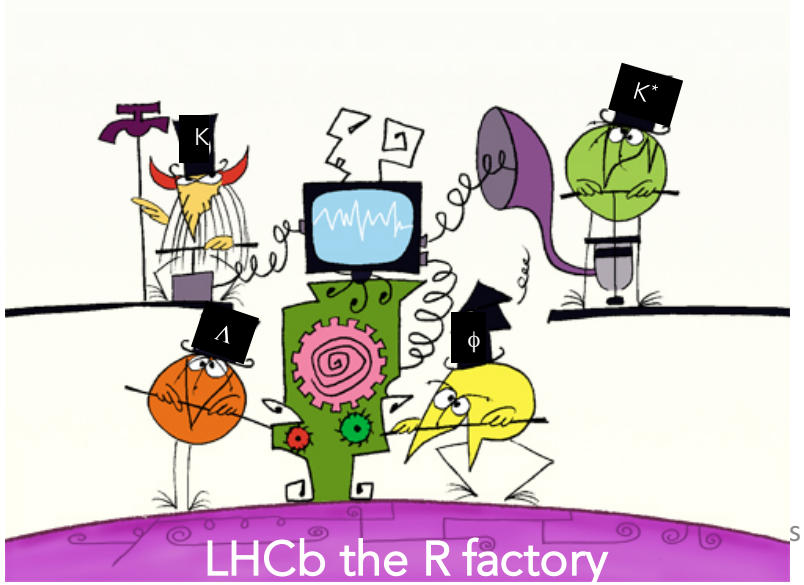
Central-q^2: 2.4 – 2.5 standard deviations

Summary

- PRD 86 (2012) 032012
- PRL 103 (2009) 171801







Mitesh talk !

Backup slides

- Fit MC to extract initial parameters
- Fit the data allowing (some) parameters to vary
- **Signal**
  - Ipatia
  - Free parameters mass shift and width scale

$\mu\mu$

- **Backgrounds**
  - Combinatorial exponential
  - Λ_b simulation & data
  - B_s same as signal but shifted by m_{Bs}-m_{B0}

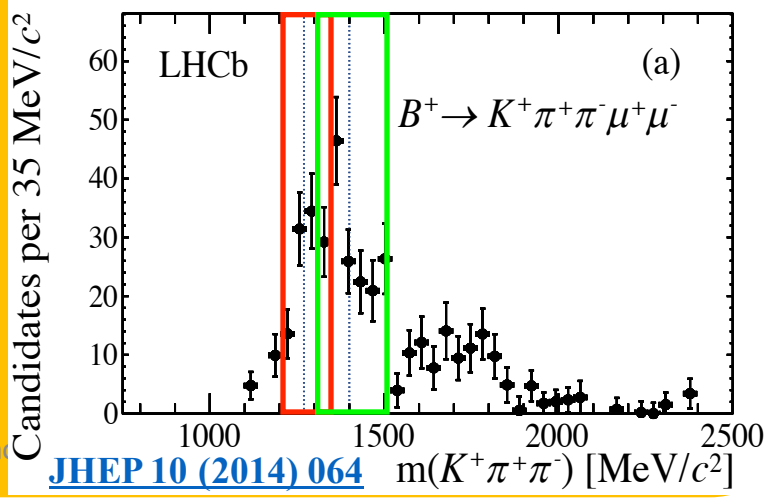
- Fit MC in different trigger and bremsstrahlung categories to extract initial parameters (separately for all modes)
- Combine bremsstrahlung PDFs into one signal model per each trigger category (bremsstrahlung fractions fixed from MC)

ee

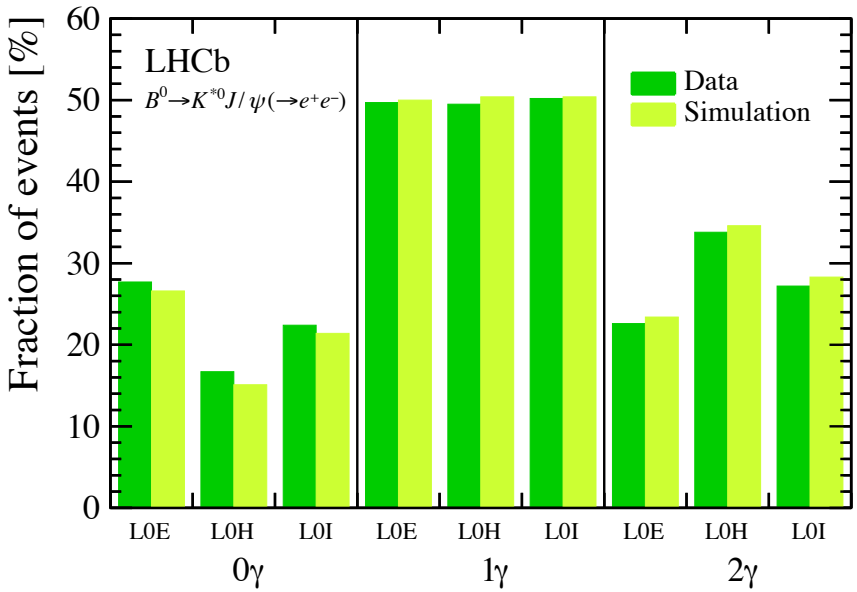
- Fit the data in trigger categories allowing (some) parameters to vary
- **Signal**
  - 0γ (1γ and 2γ) — Crystal-Ball (Crystal-Ball and Gaussian)
  - Free parameters — mass shift and width scale
- **Backgrounds**
  - Combinatorial — exponential
  - Λ_b — simulation & data, yield constrained using muons
  - B_s — same as signal but shifted by m_{Bs}-m_{B0}, yield constrained using muons
  - Leakage — simulation, yield constrained using data
  - Part-Reco — simulation & data

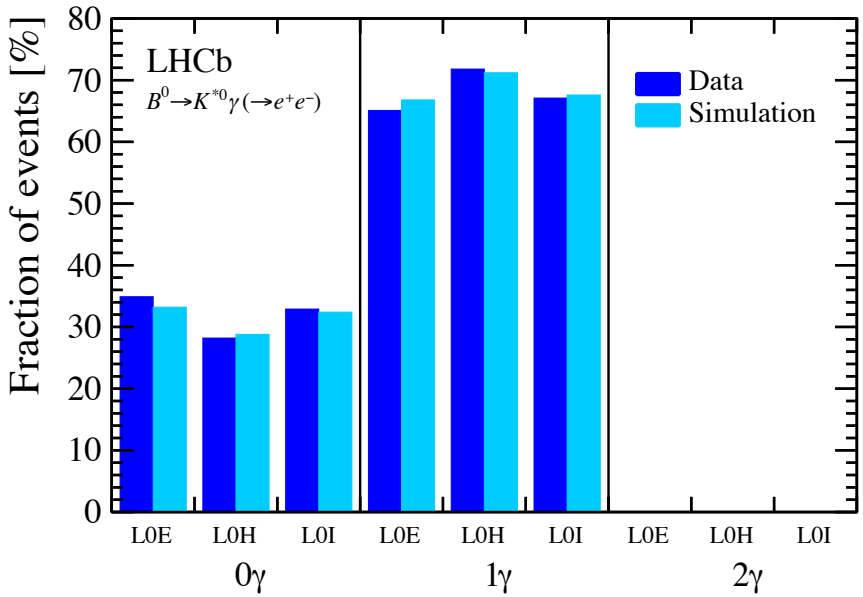
* Create a K_1+K_2 cocktail from simulation but using data to determine the relative fraction

* Use sPlotted data from LHCb-PAPER-2014-030 to re-weight $B \to K\pi\pi ee$ simulated events



JHEP 10 (2014) 064


LHCb
$B^0 \to K^{*0} J/\psi(\to e^+e^-)$
Data
Simulation
Fraction of events [%]
0
10
20
30
40
50
60
L0E
L0H
L0I
0γ
1γ
2γ


LHCb
$B^0 \to K^{*0} \gamma(\to e^+e^-)$
Data
Simulation
Fraction of events [%]
0
10
20
30
40
50
60
70
80
L0E
L0H
L0I
0γ
1γ
2γ

- **Selection steps**
  - Pre-selection requirements on trigger and quality of the candidates
  - Cuts to remove the peaking backgrounds
  - Particle identification to further reduce the background
  - Multivariate classifier to reject the combinatorial background
  - Kinematic requirements to reduce the partially-reconstructed backgrounds
  - Multiple candidates randomly rejected

On the low q^2 region and the hadronic resonances :

In the SM $R_{K^*} \sim 0.90$, we are in a regime where electrons and muons are very similar

V	BR(V→ee)	BR(V→μμ)	BR(B^0→K*V)	BR(B^0→K*V(ee))	BR(B^0→K*V(μμ))
ϕ	$(2.95 \pm .03)\ 10^{-4}$	$(2.87 \pm .19)\ 10^{-4}$	$(1.00 \pm .05)\ 10^{-5}$	$(29.5 \pm 1.5)10^{-10}$	$(28.7 \pm 2.4)\ 10^{-10}$
ρ	$(4.72 \pm .05)\ 10^{-5}$	$(4.55 \pm .28)\ 10^{-5}$	$(3.9 \pm 1.3)\ 10^{-6}$	$(1.84 \pm 0.61)10^{-10}$	$(1.77 \pm 0.60)\ 10^{-10}$
ω	$(7.28 \pm .14)\ 10^{-5}$	$(9.0 \pm 3.1)\ 10^{-5}$	$(2.0 \pm .5)\ 10^{-6}$	$(1.46 \pm 0.37)10^{-10}$	$(1.8 \pm 0.77)\ 10^{-10}$

ϕ : larger product of BR, no lepton mass effect

ρ : product of BR significantly smaller than the ϕ.
wide resonance : interference ? But should be the same for electrons and muons

ω : significantly smaller than the ϕ

We are not subtracting these backgrounds ; if anything they should increase the measured value of R_{K^*}

V	BR(V→ee)	BR(V→μμ)	BR(B^0→K*V)	BR(B^0→K*V(ee))	BR(B^0→K*V(μμ))
η	< 2.3 10^{-6}	(5.8 ± .8) 10^{-6}	(1.59 ± .10) 10^{-5}	< 0.4 10^{-10}	(9.2 ±)10^{-10}

BR(η→eeγ) = (6.9 ± 0.4) 10^{-3}

BR(η→μμγ) = (0.31 ± 0.04) 10^{-3}

One missing photon → in the partially reconstructed background

arXiv:1212.2263