Lepton Flavour Universality Tests at LHCb

Vinícius Franco Lima
On Behalf of LHCb Collaboration
Lyon, IPNL, 18/04/18

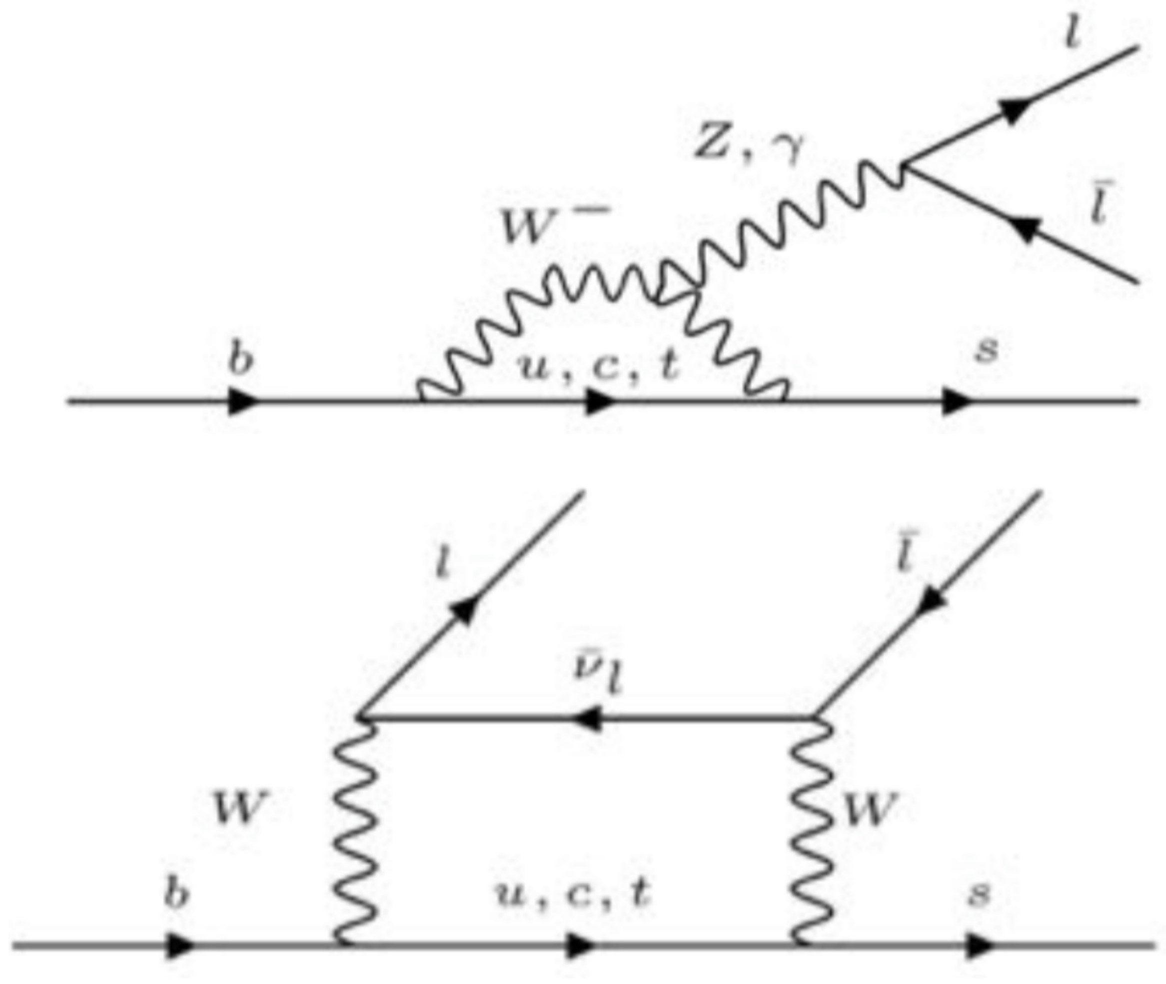
Lepton Flavour Universality

In the SM, leptons from different families have the same coupling to W and Z bosons.

It is possible to probe the effective couplings in decays of B hadrons in different tree level and FCNC processes.

Measurements using ratios of B decays cancel many of the theoretical uncertainties.

This talk will cover LFU studies in LHCb using $3fb^{-1}$ @ 7/8 TeV



+ NP Contributions?

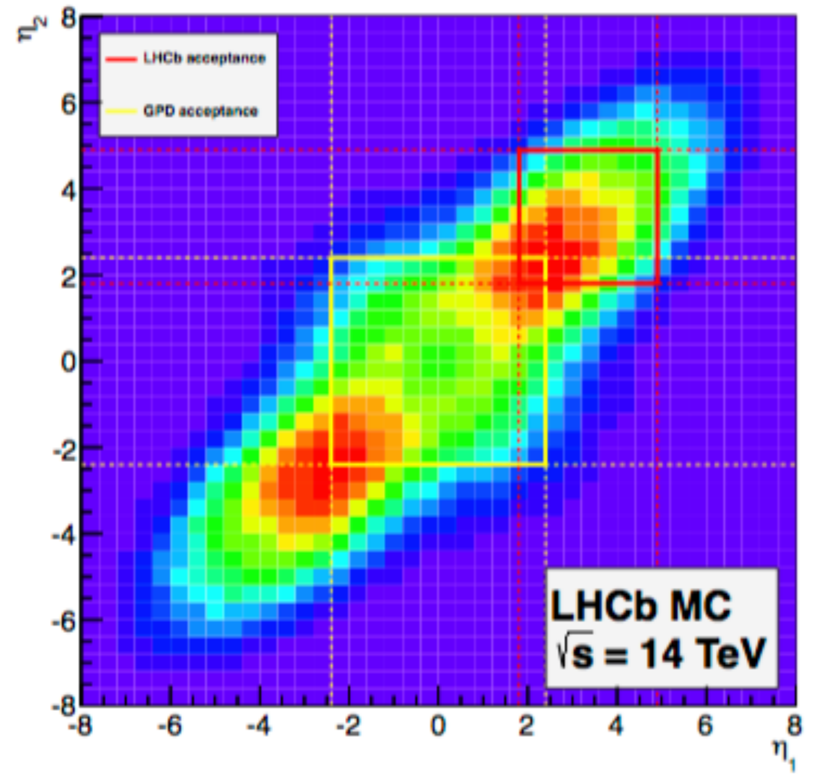
LHCb Detector

Excellent vertex resolution

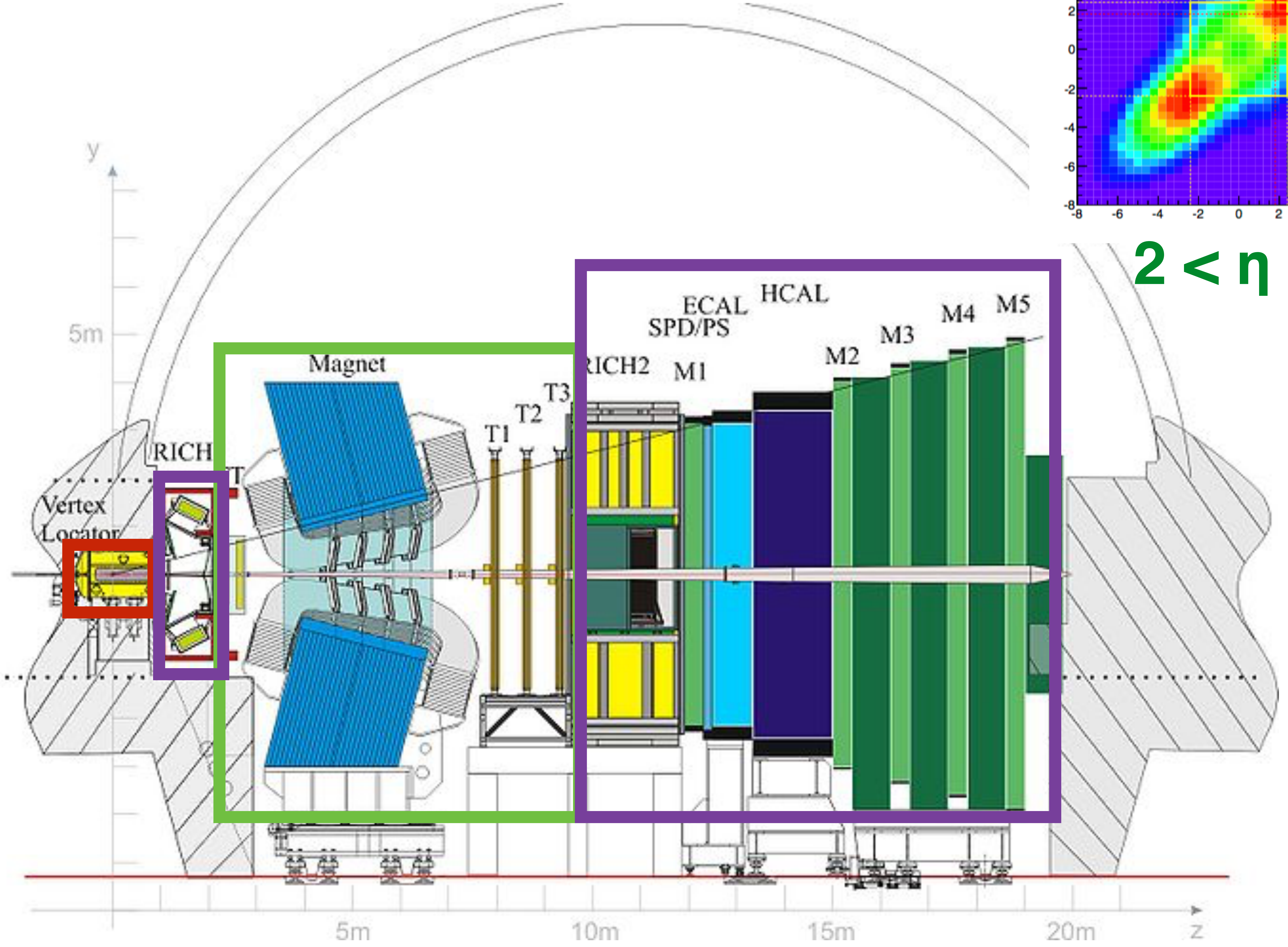
IP_x Resolution: 13μm
Decay Time: ~50fs

Excellent tracking and momentum resolution.

Excellent particle identification capabilities.



2 < η < 5



Int. J. Mod. Phys. A **30**, 1530022 (2015)

LHCb Detector

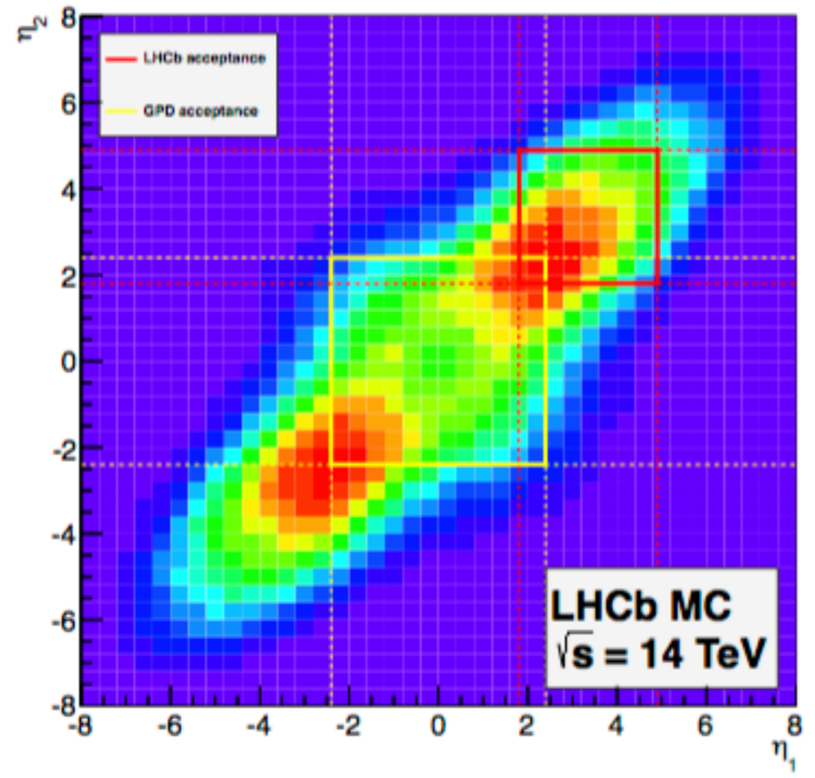
Excellent vertex resolution

Excellent tracking and momentum resolution.

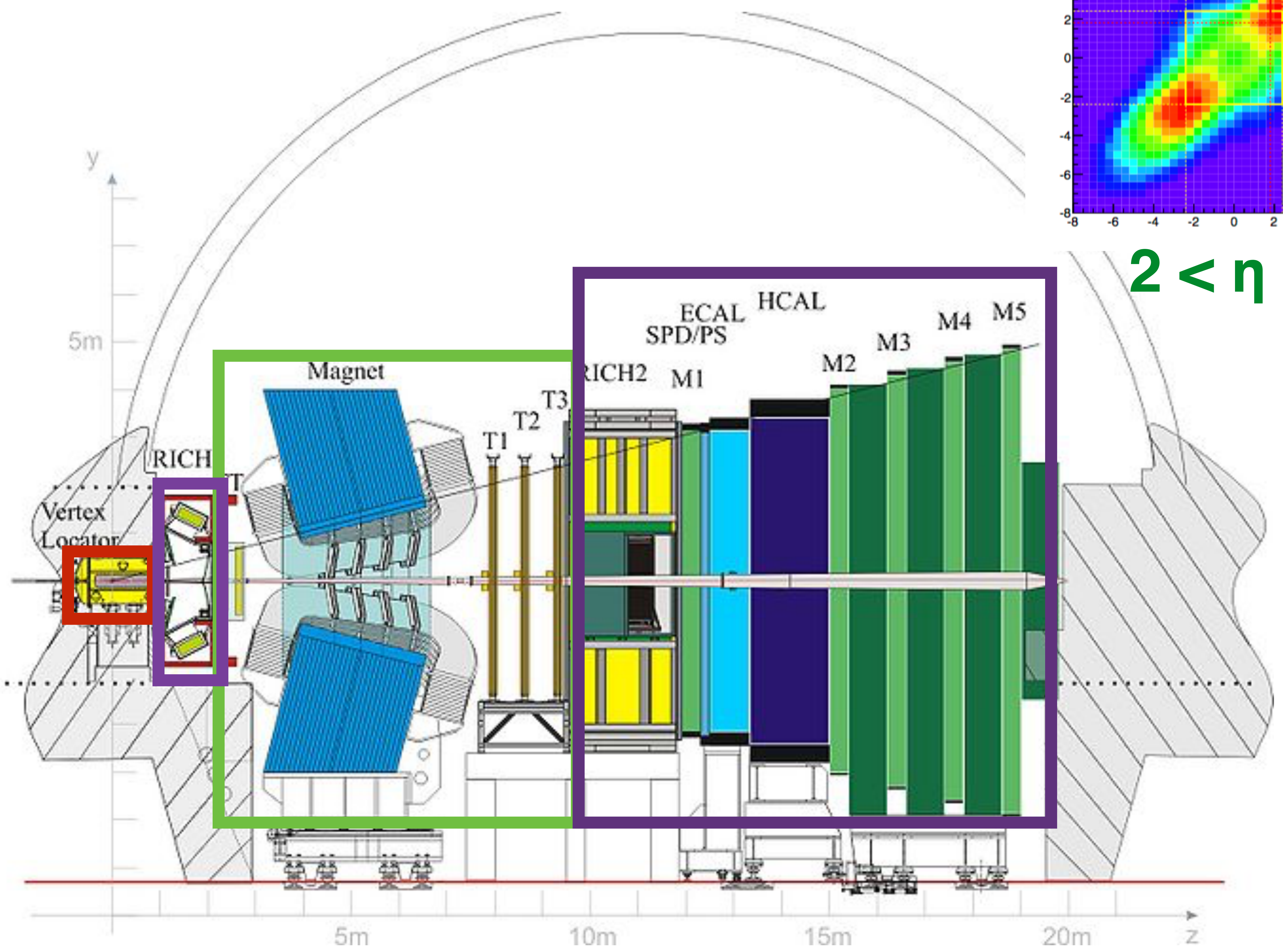
$\Delta p/p \sim 0.4 - 0.6\%$

Excellent particle identification capabilities.

RICH K-π-p ID
99% efficiency μ ID
Calo e-gamma ID



$2 < \eta < 5$



Int. J. Mod. Phys. A **30**, 1530022 (2015)

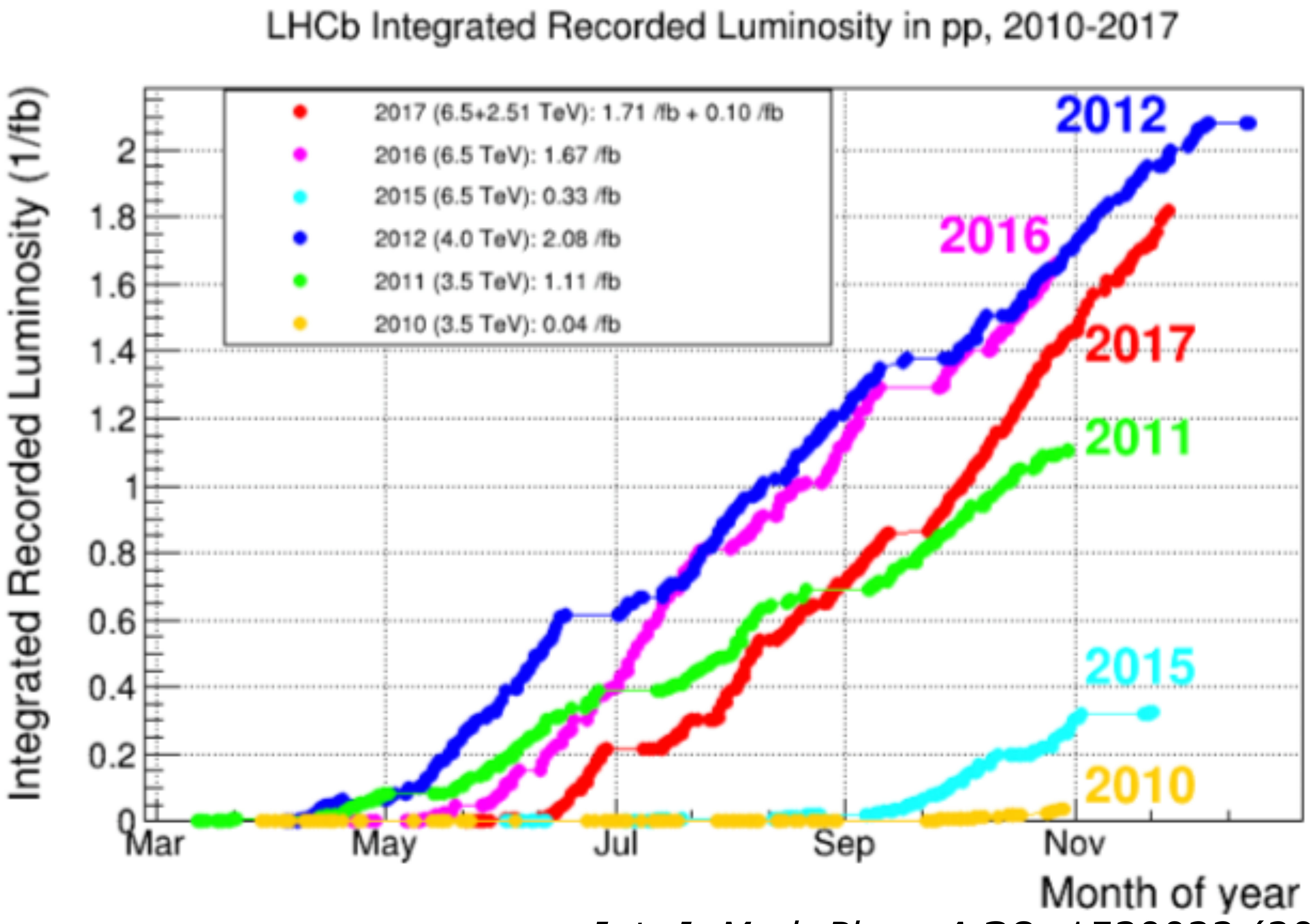
LHCb Detector

Excellent vertex resolution

Excellent tracking and momentum resolution.

Excellent particle identification capabilities.

~7fb^{-1} of data so far!



Int. J. Mod. Phys. A **30**, 1530022 (2015)

LFU in Tree Level Processes

R(J/ψ)

$$\mathcal{R}(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi\,\tau^+\nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi\,\mu^+\nu_\mu)}$$

Identical Reconstructed Final state: $\mu^+\ \mu^-\ \mu^+$

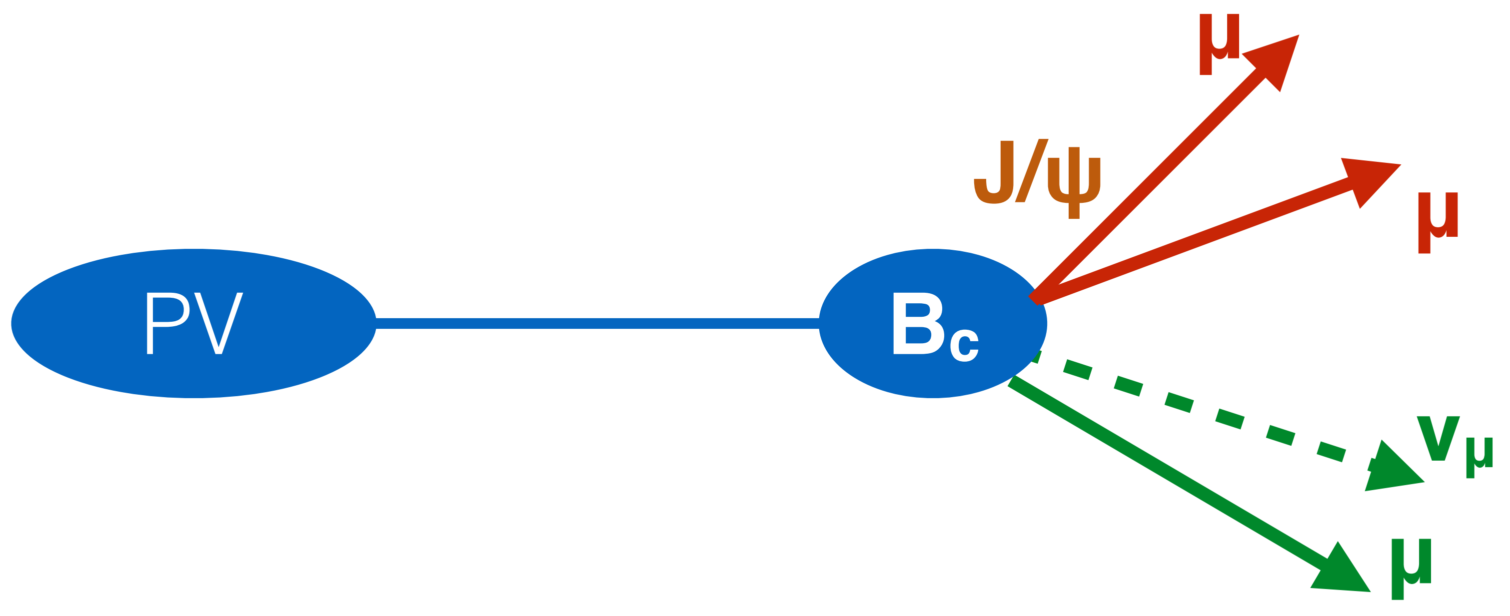
Main Backgrounds:

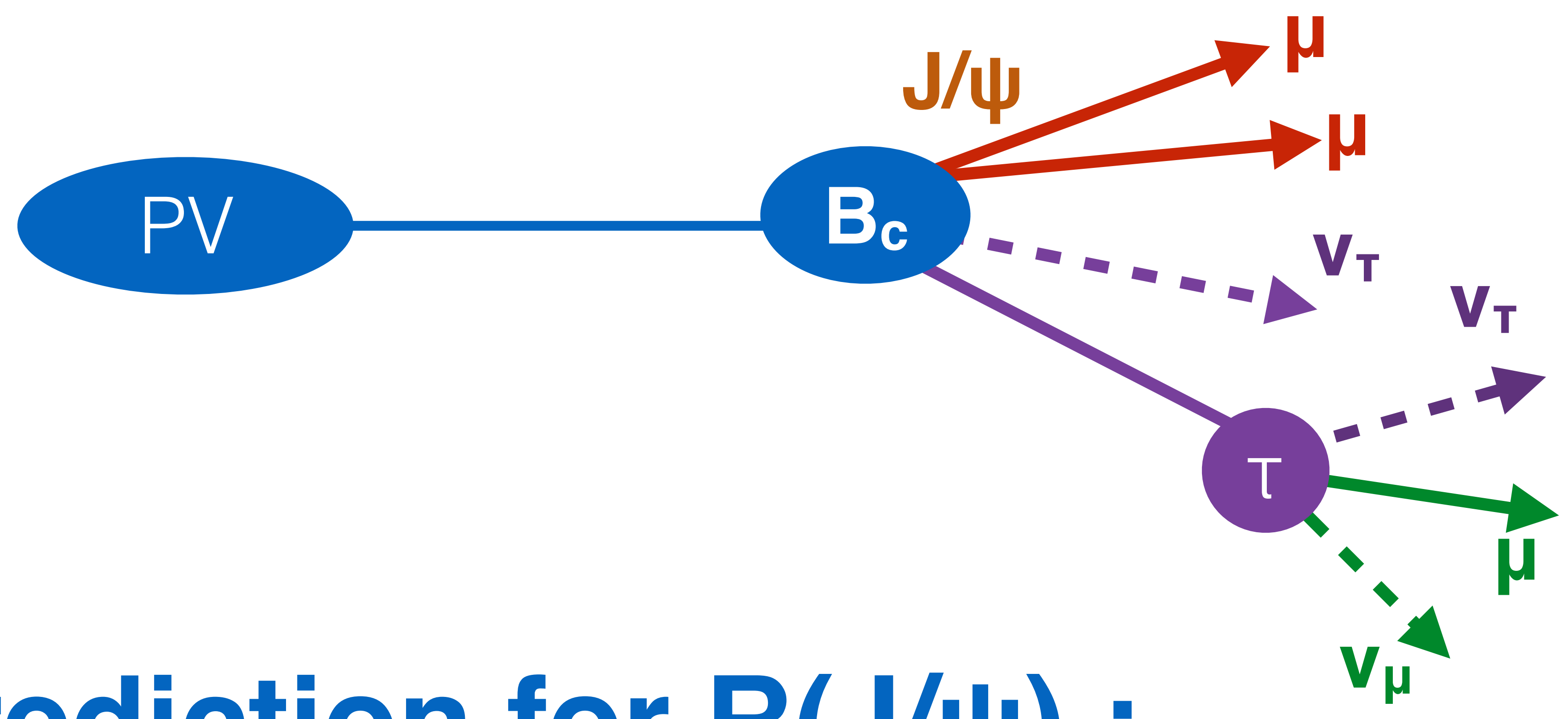
$B \to J/\psi\ h$; h misID as μ

$B_c \to J/\psi\ D(\mu\nu\ X)X$

$J/\psi\ \mu$ Combinatorial Bkg

Analysis using $3 fb^{-1}$ Run 1 data





SM Prediction for R(J/ψ) : 0.25- 0.28 (ref in backup)

Phys. Rev. Lett. **120**, 121801

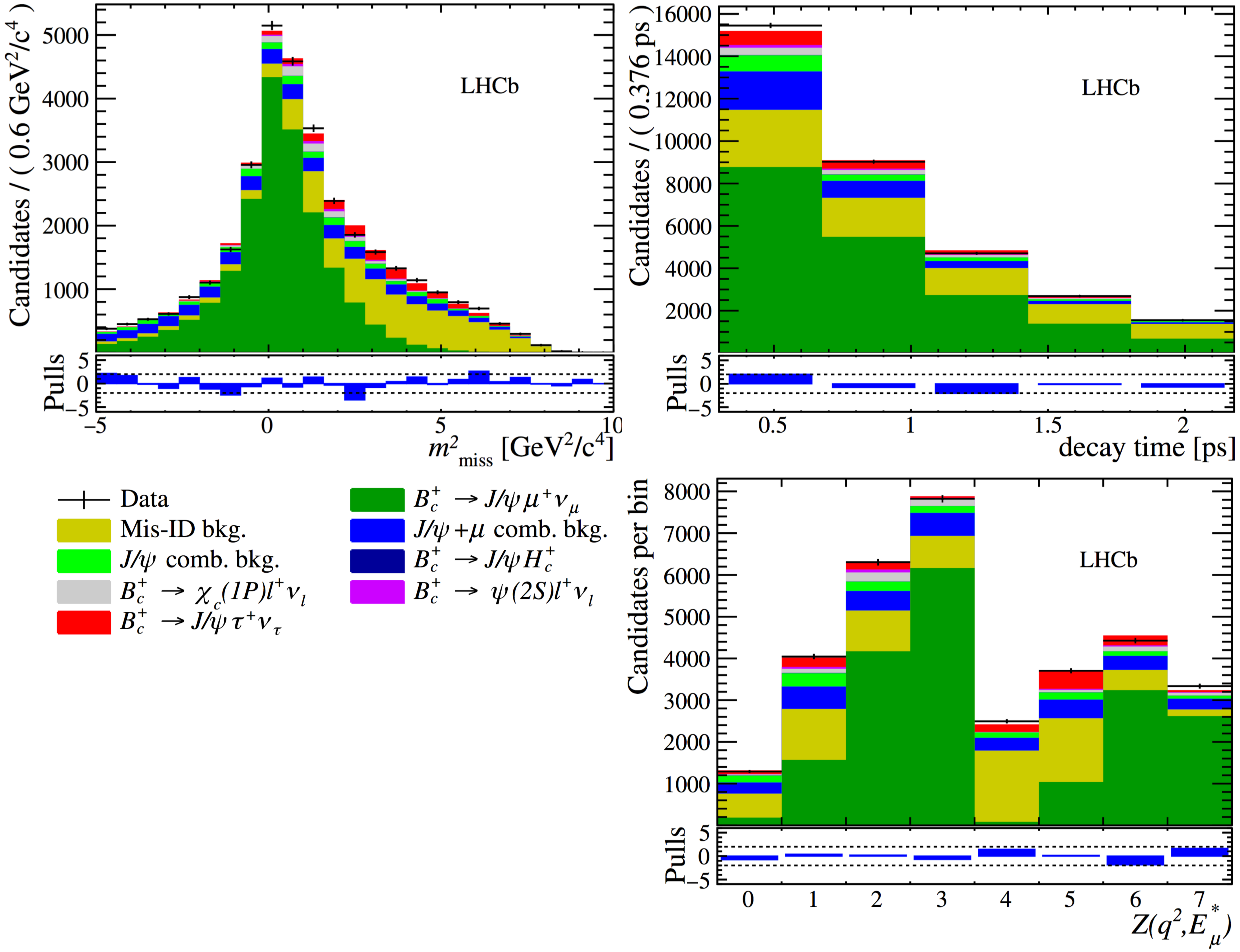
R(J/ψ)

In order to calculate signal yield a template fit is used.

Simultaneous fit in m^2_{miss}, B_c lifetime and $Z(E_\mu, q^2)$

Z is a categorical variable separating candidates in bins of E_μ and q^2

Tau decay m^2_{miss} softer due to 3 missing neutrinos compared to1 in the μ case.



Phys. Rev. Lett. **120**, 121801

R(J/ψ)

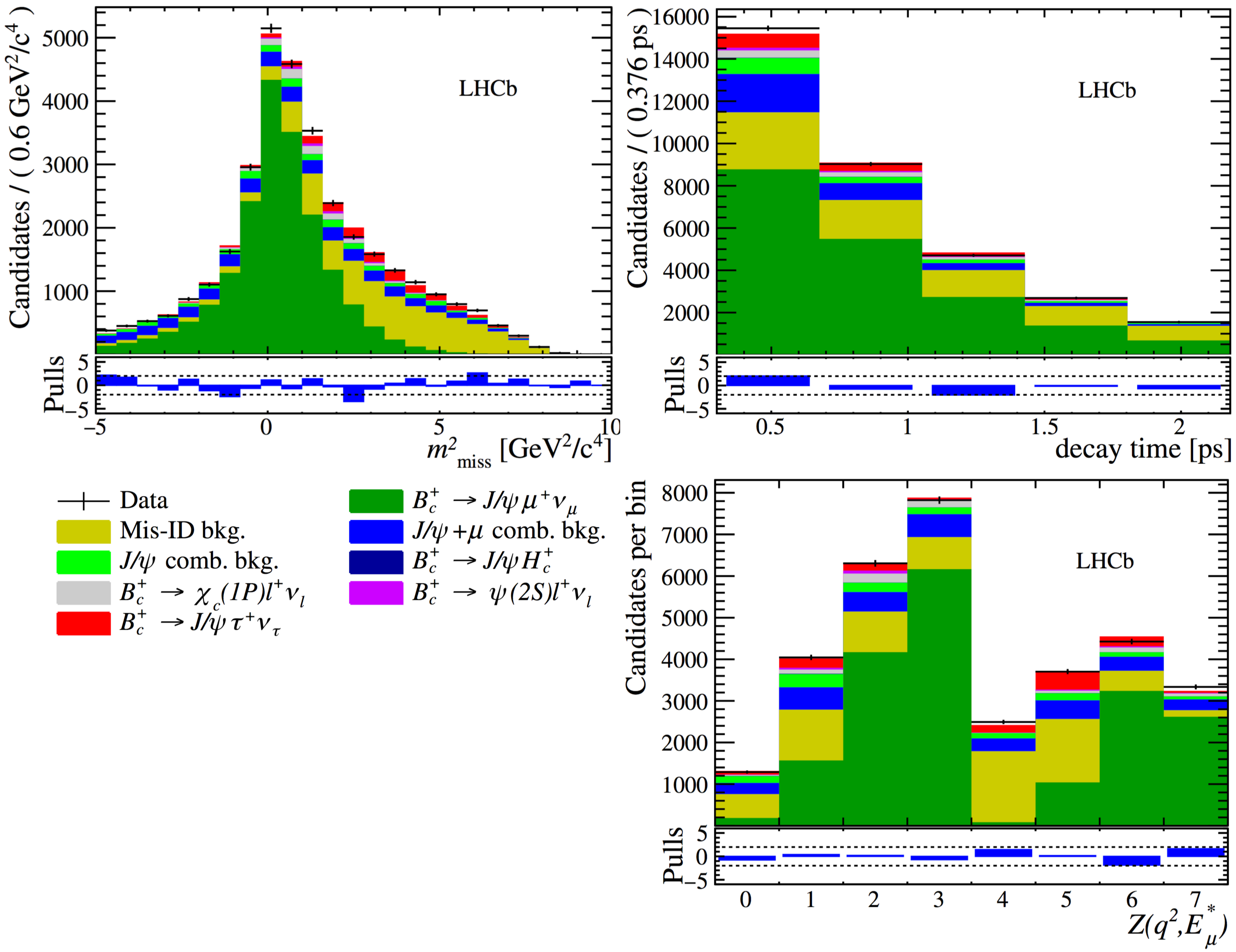
In order to calculate signal yield a template fit is used.

$$\mathcal{R}(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

$$= 0.71 \pm 0.17(\mathrm{stat}) \pm 0.18(\mathrm{syst})$$

Systematic uncertainties dominated by $B_c \to J/\psi$ form factors and simulation size.

Result lies within 2σ of prediction from SM.



Phys. Rev. Lett. **120**, 121801

R(D*)

Use tree-level semileptonic decays to probe possible NP couplings.

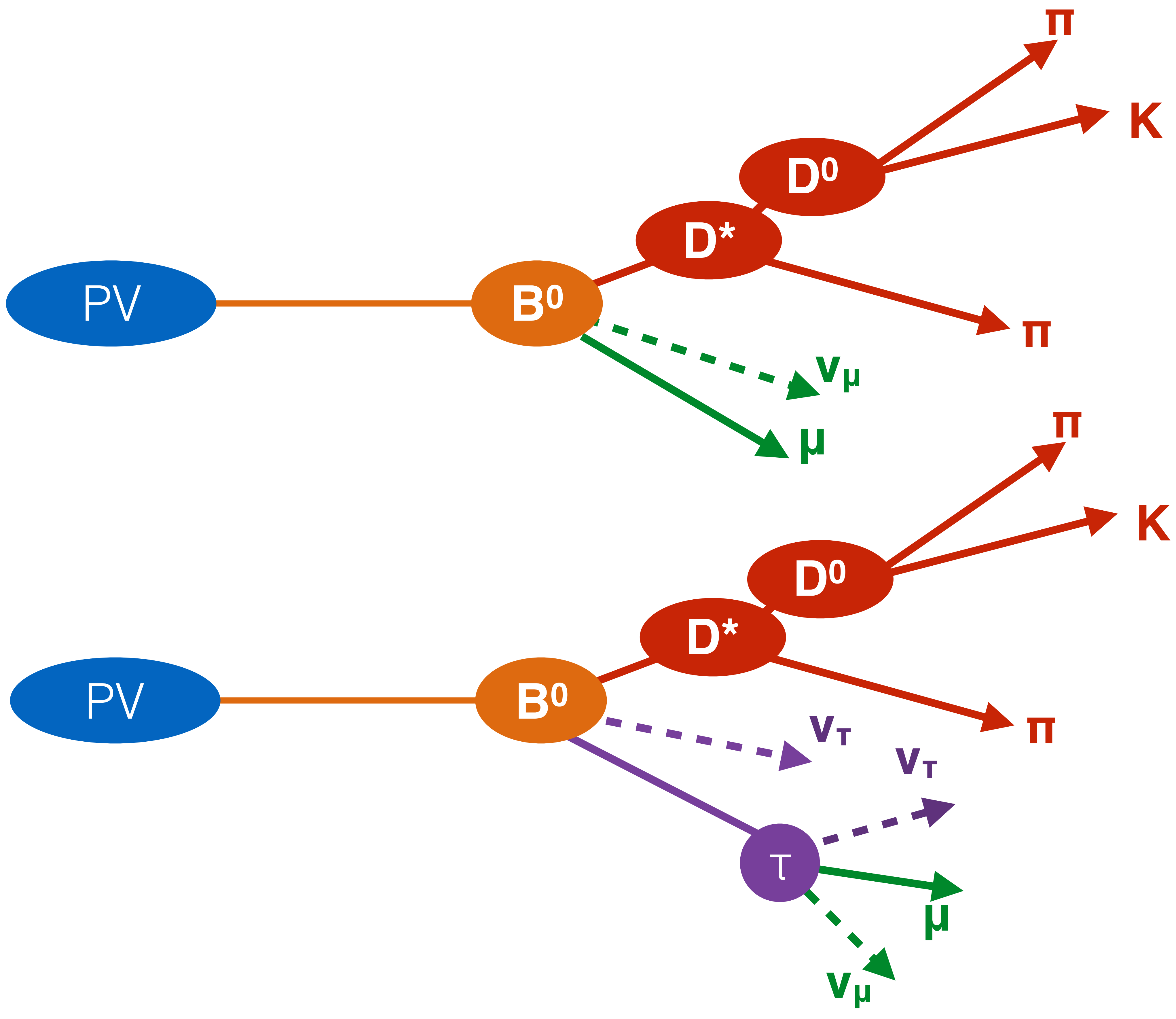
$$R(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

R(D*) SM ratio: 0.252±0.003

Phys. Rev. D **85**, 094025 (2012)

Main Backgrounds:

B→Charmed Hadrons (DD*)
B →Dlv**



PRL 115 (2015) 111803

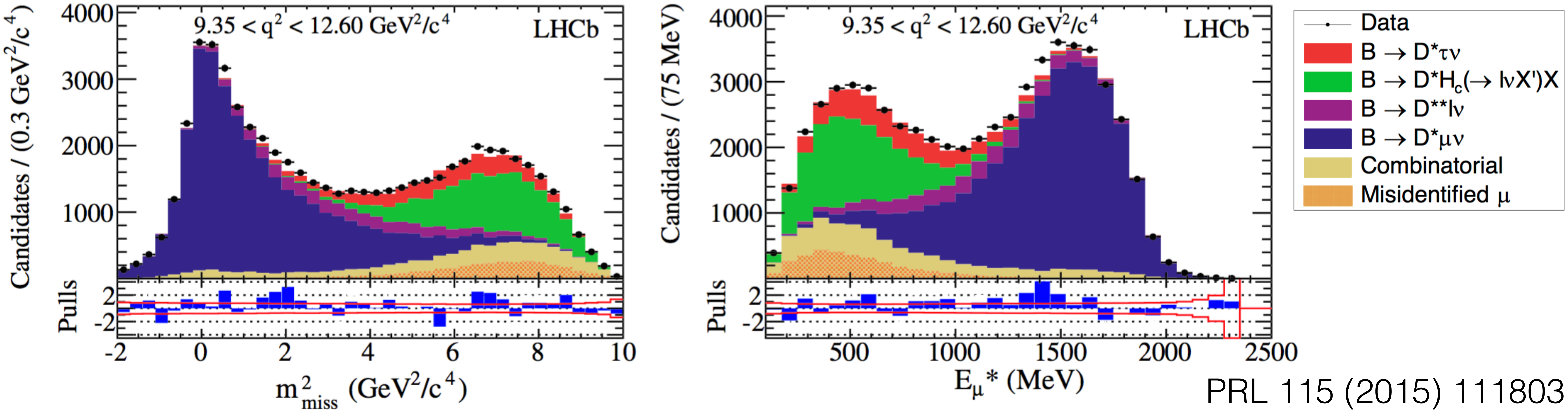
R(D*)

Signal extracted by 3D template fit (q^2, m^2_{miss}, E_μ).

Main source of systematic uncertainties is sample size for template generation.

Template obtained from simulated distributions.

$$\mathcal{R}(D*) = 0.336 \pm 0.027(\text{stat}) \pm 0.030(\text{syst})$$



PRL 115 (2015) 111803

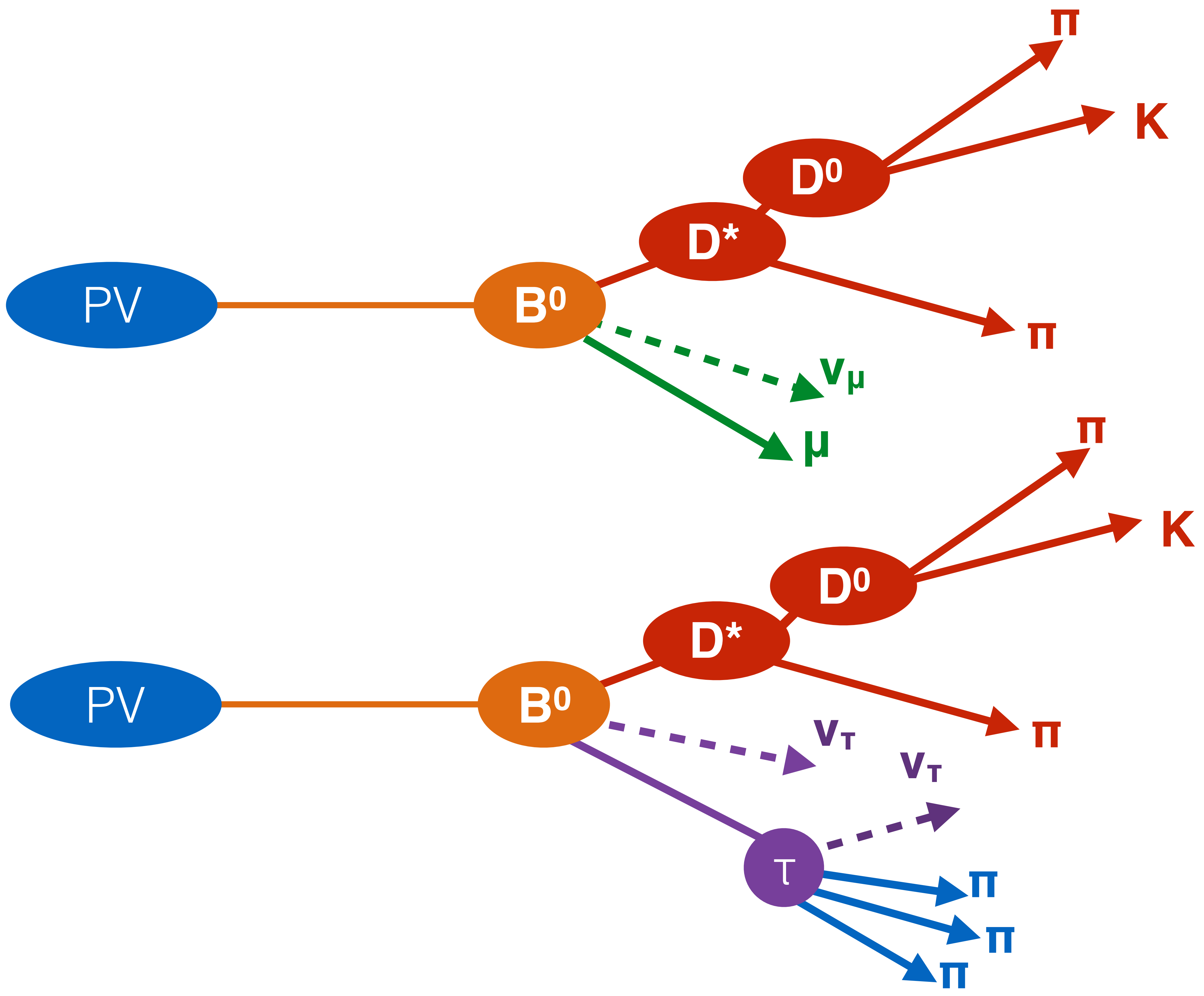
R(D*) - Hadronic

Use the hadronic τ decay into 3 charged π.

Charged tracks allow vertexing for identifying τ decay point.

Use already measured BF of to obtain R(D*) from the relative measurement:

$$\mathcal{K}(D^{*-}) \equiv \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}3\pi)}$$



$B^0 \to D^{*-}3\pi$ and $B^0 \to D^{*-}\mu\nu$, already measured.

PRD85 (2012) 094025

R(D*) - Hadronic

Use the hadronic τ decay into 3 charged π.

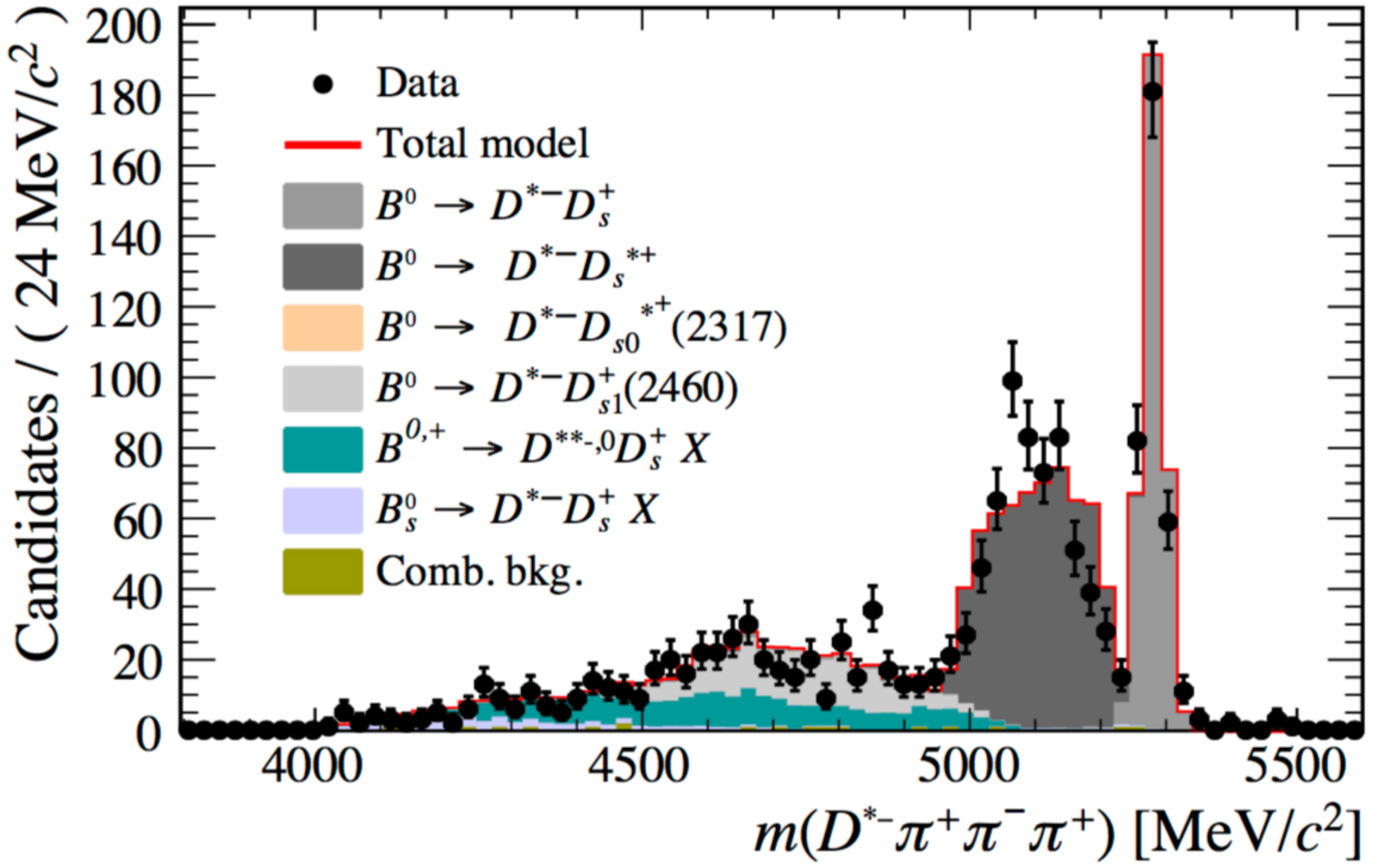
Yields extracted from a fit to q², τ lifetime and kinematical BDT.

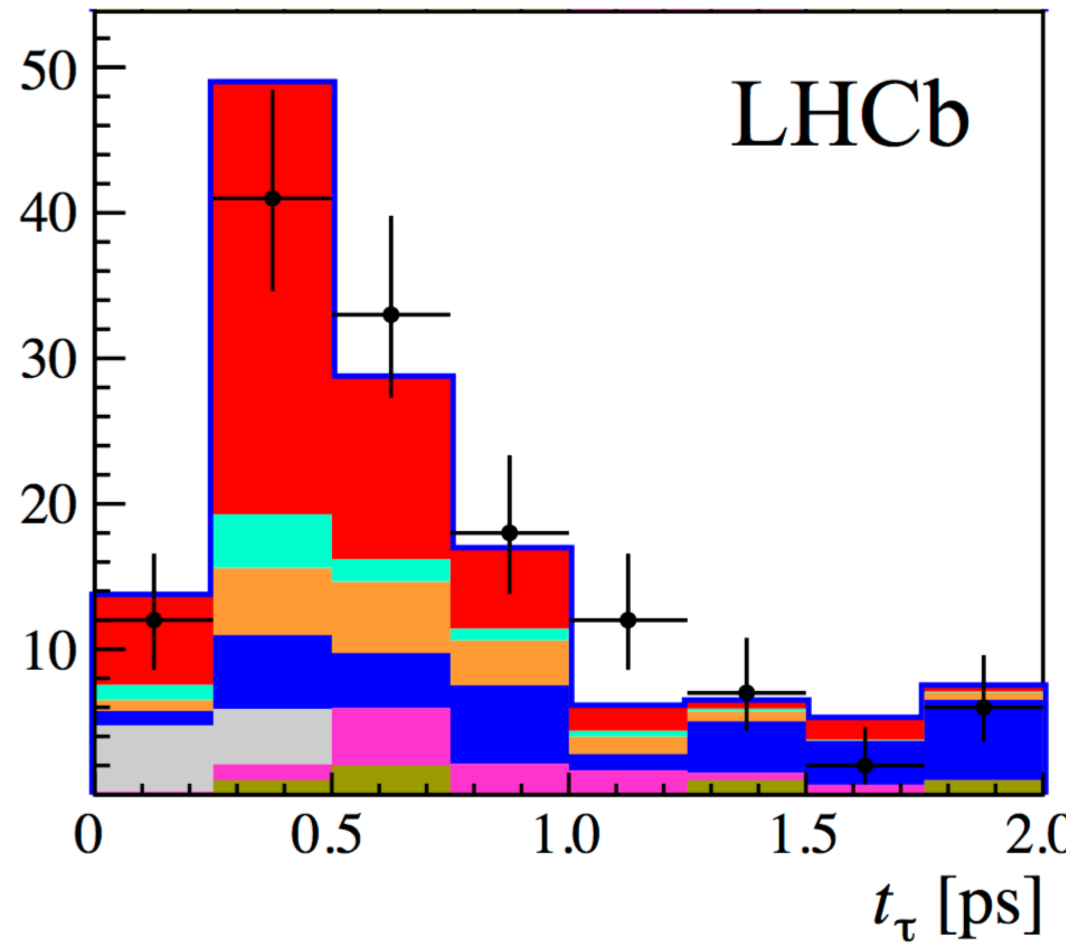
Using:

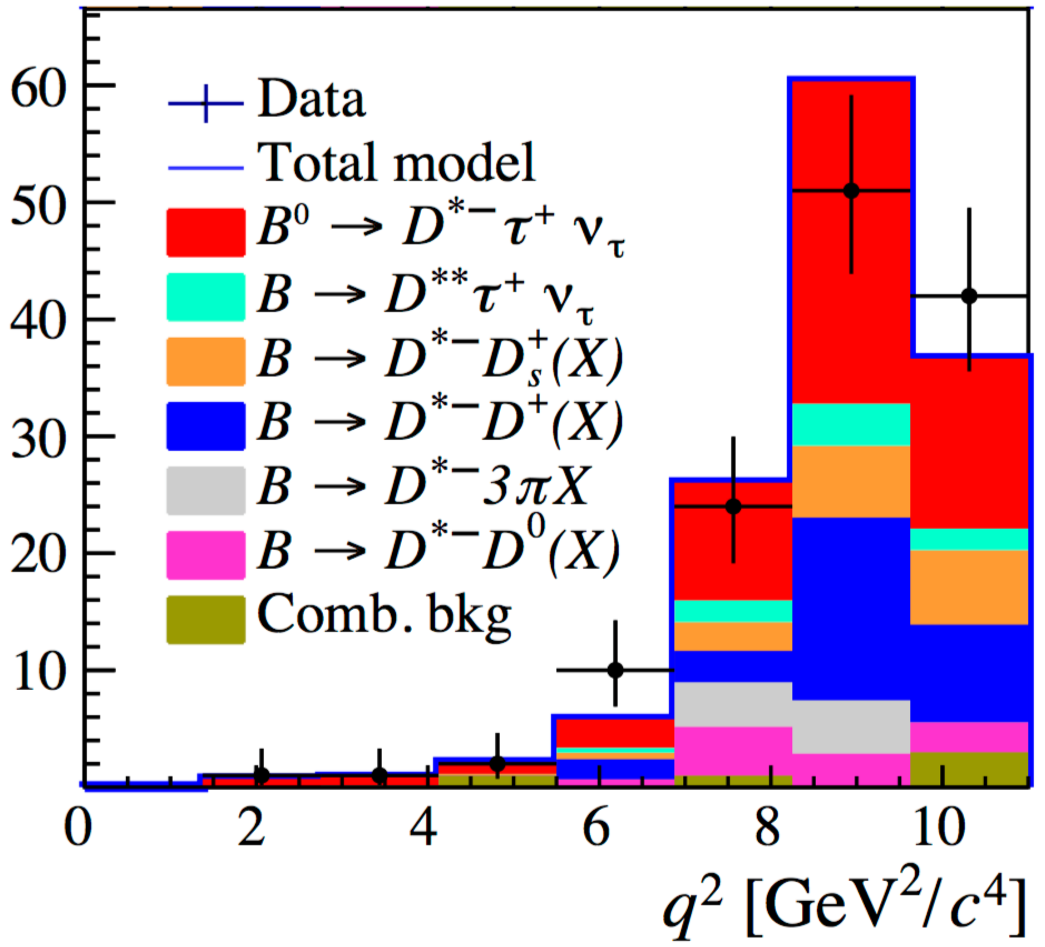
$$\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu) = (4.88 \pm 0.10) \times 10^{-2}$$
$$\mathcal{B}(B^0 \to D^{*-}3\pi) = (7.23 \pm 0.51) \times 10^{-3}$$

$$\mathcal{R}(D^{*-}) = 0.286 \pm 0.019\,(\text{stat}) \pm 0.025\,(\text{syst}) \pm 0.021\,(\text{ext})$$

Control Mode





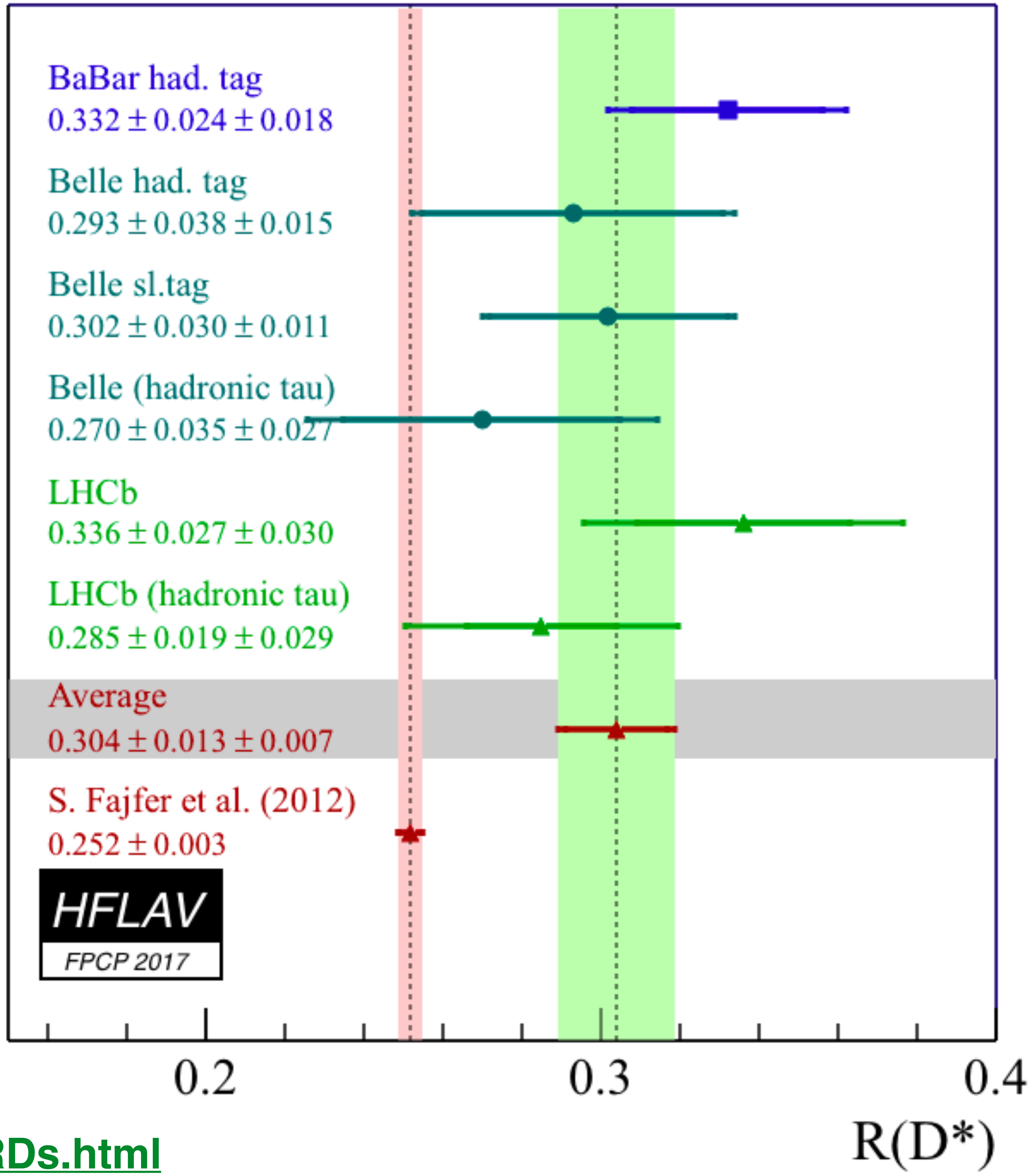


Phys. Rev. D **87**, 092001 Eur. Phys. J. C77 (2017) 895 PRD85 (2012) 094025

R(D*) Status

LHCb results have been incorporated on world average compilation.

Currently R(D*) shows a tension of 3.4σ with respect to SM prediction.



http://www.slac.stanford.edu/xorg/hflav/semi/fpcp17/RDRDs.html

LFU in FCNC Processes

LFU probed with b→sll

Small BR due to FCNC being forbidden in SM at tree level.

NP could produce a noticeable deviation from SM.

Different hadrons H are sensitive to different Wilson Coefficient combinations.

$$R_H \equiv \frac{\int_{4m_\mu^2}^{q^2_{\max}} dq^2 \frac{d\Gamma(B \to H\mu^+\mu^-)}{dq^2}}{\int_{4m_\mu^2}^{q^2_{\max}} dq^2 \frac{d\Gamma(B \to He^+e^-)}{dq^2}}$$

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) \mathcal{O}_i(\mu)$$

arXiv:1411.4773 arXiv:hep-ph/0310219

R(K)

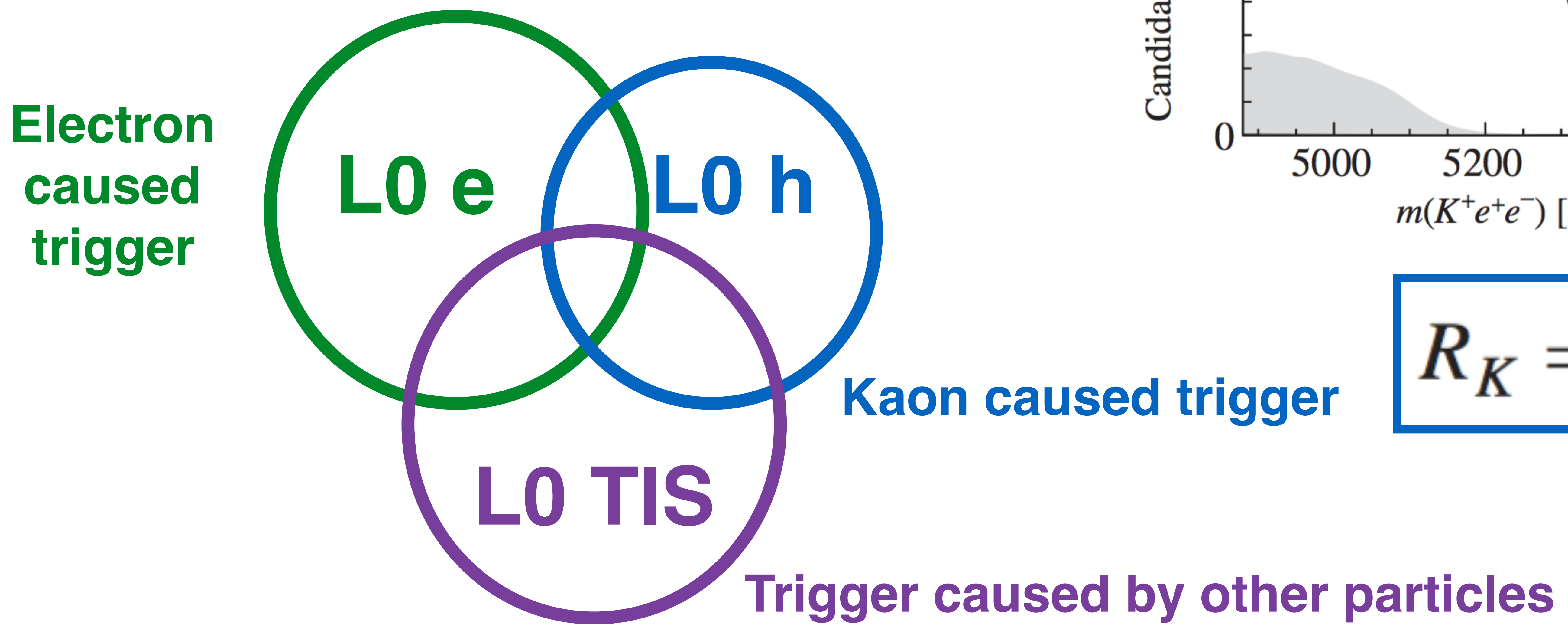
R(K) in SM = 1.0029
e.g. PRL 111, 162002 (2013)

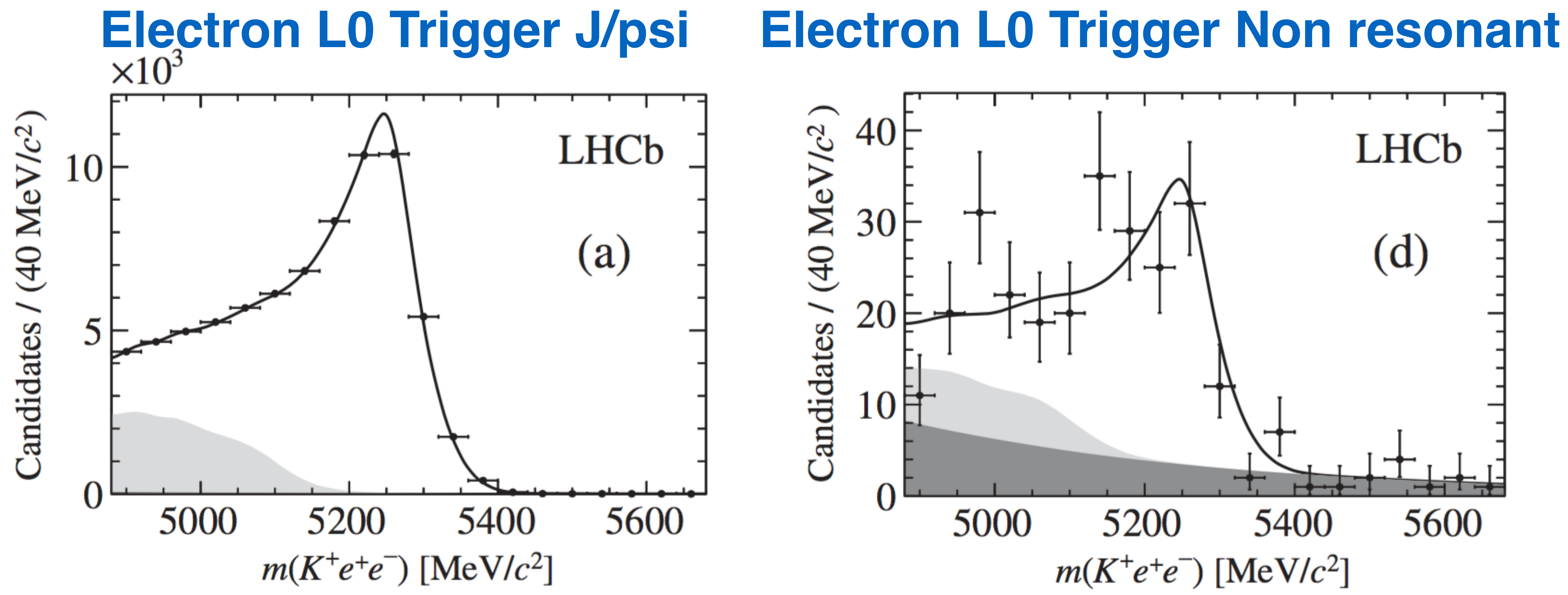
Measured using a double ratio

$1 < q^2 < 6$ GeV^2/c^4

Events treated independently by trigger category.

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+J/\psi(\to \mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to K^+J/\psi(\to e^+e^-))}$$





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

2.6 σ from the SM!

PRL 113, 151601 (2014)

JHEP 08 (2017) 055

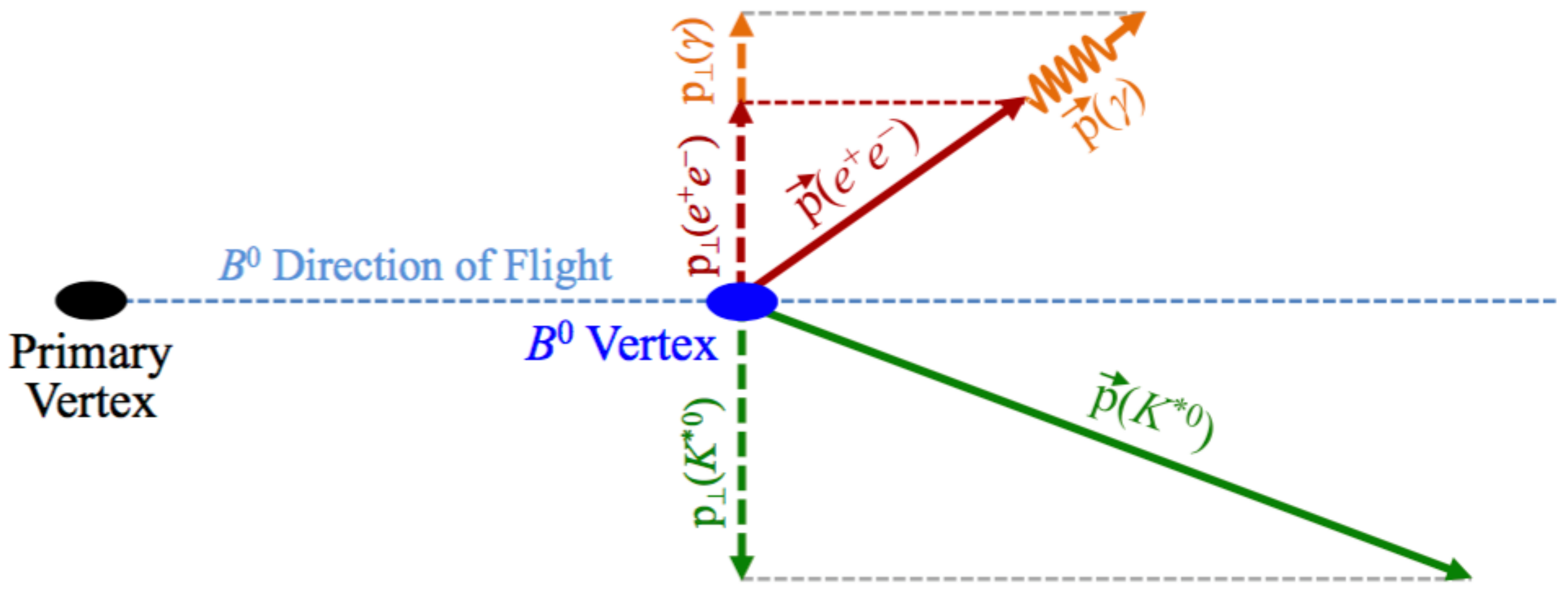
R(K*)

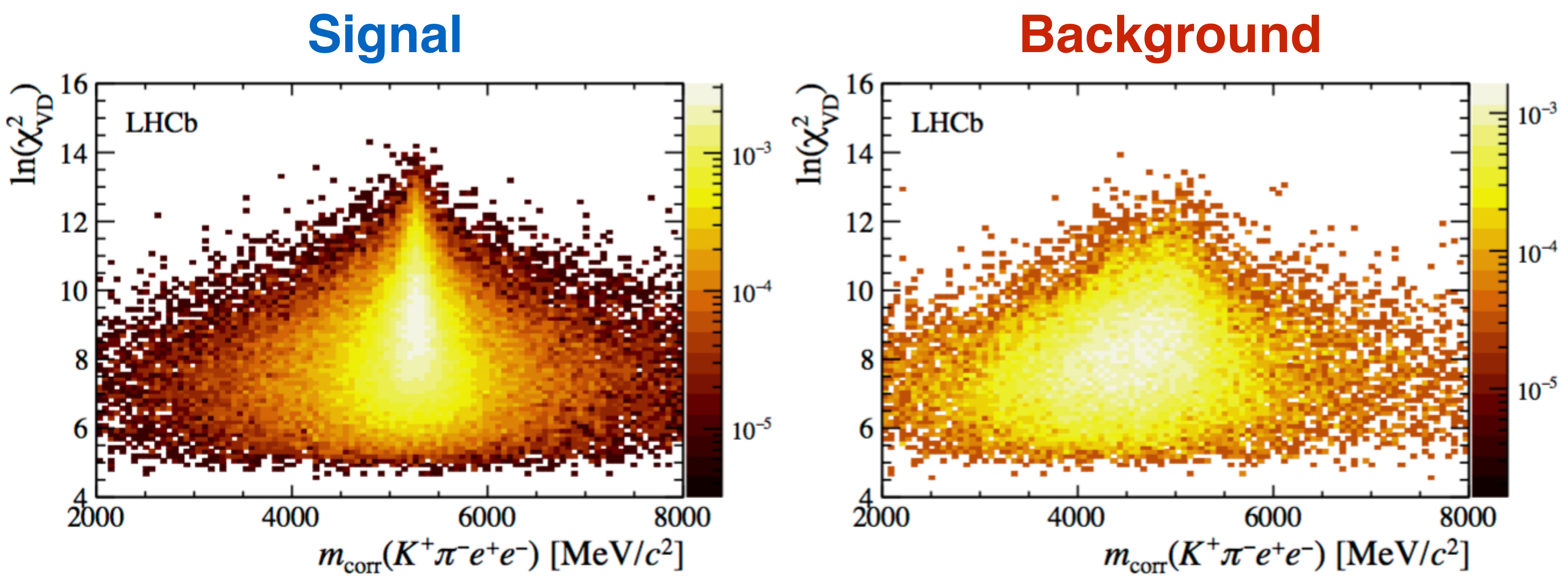
Also using a double ratio method.

4 body final state, K* reconstructed as K-π

Use the measured B direction of flight to correct for electron Brem losses.

Corrected mass used as discriminant





JHEP 08 (2017) 055

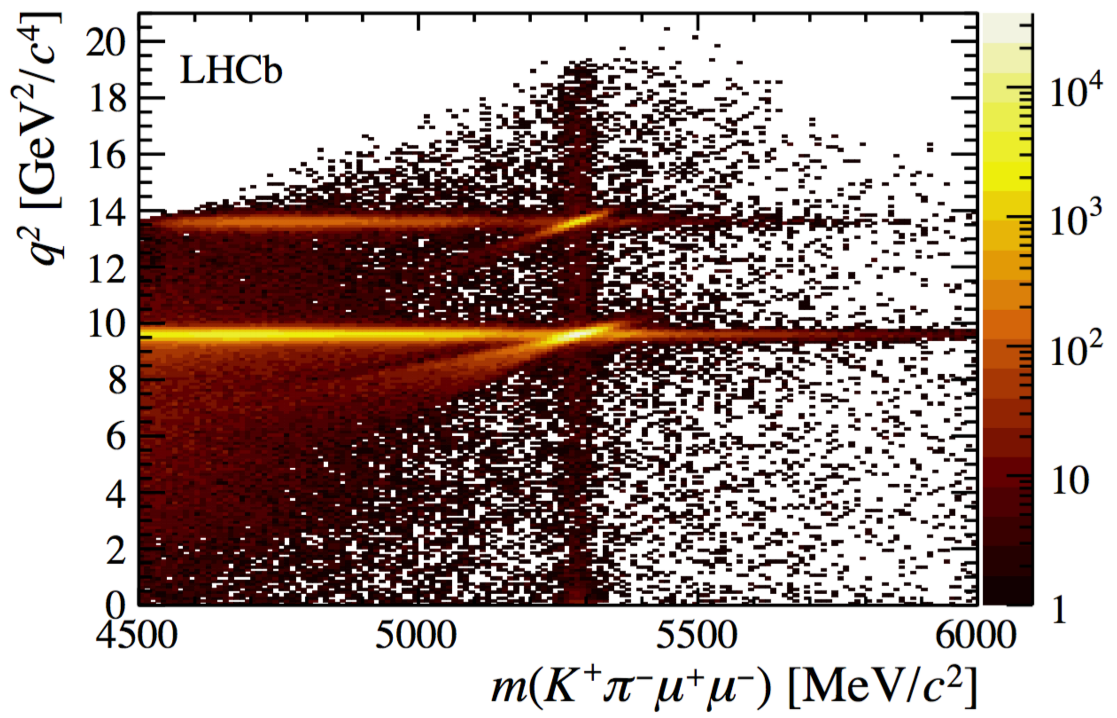
R(K*)

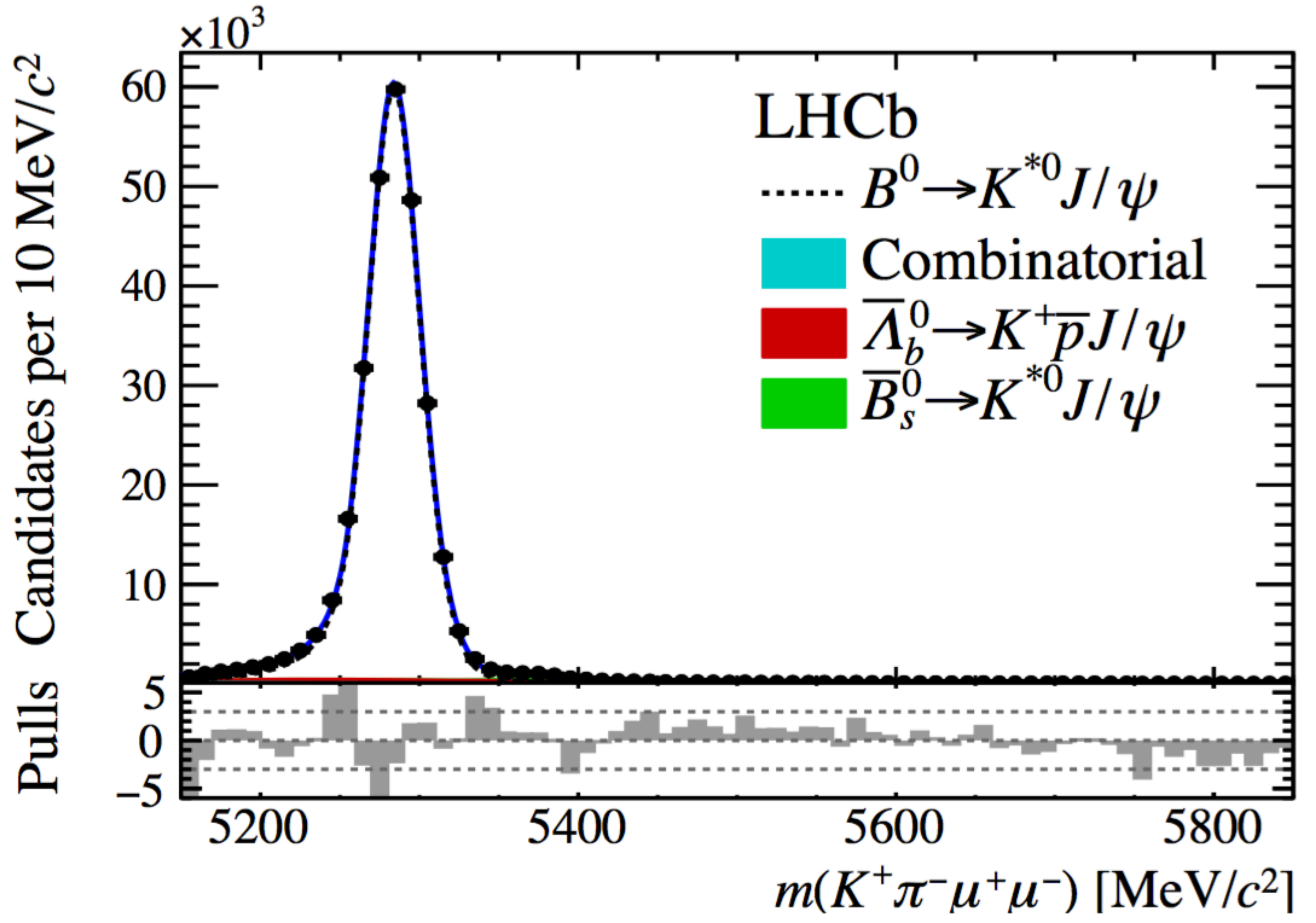
Also using a double ratio method.

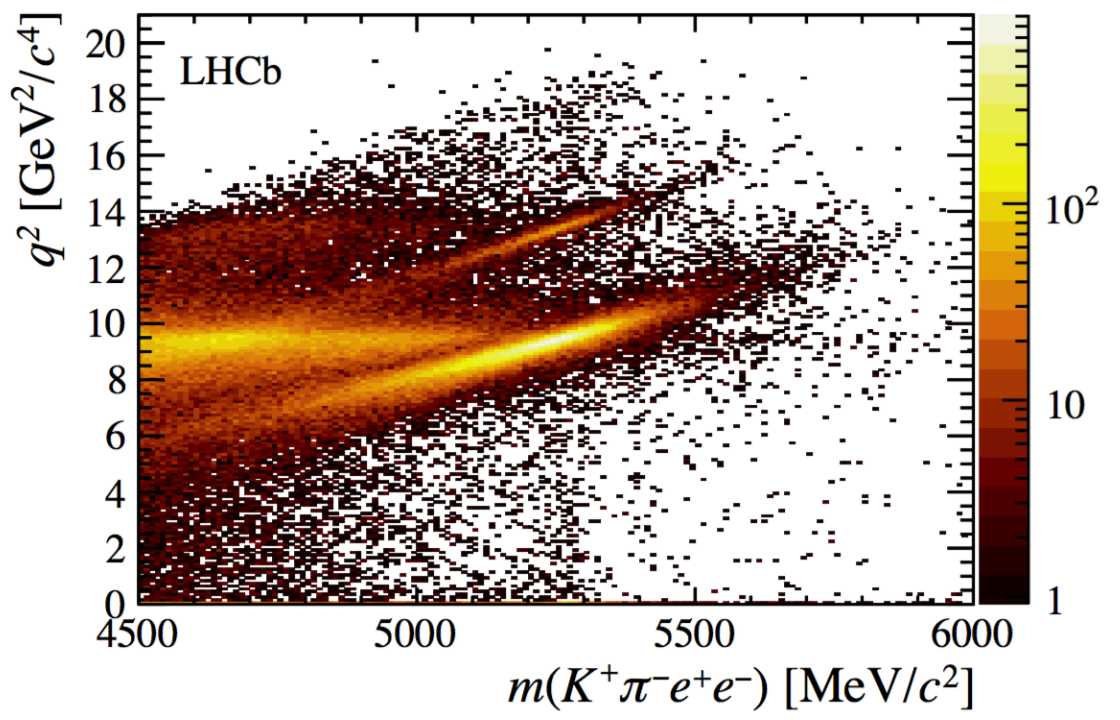
Measured in two q^2 regions.

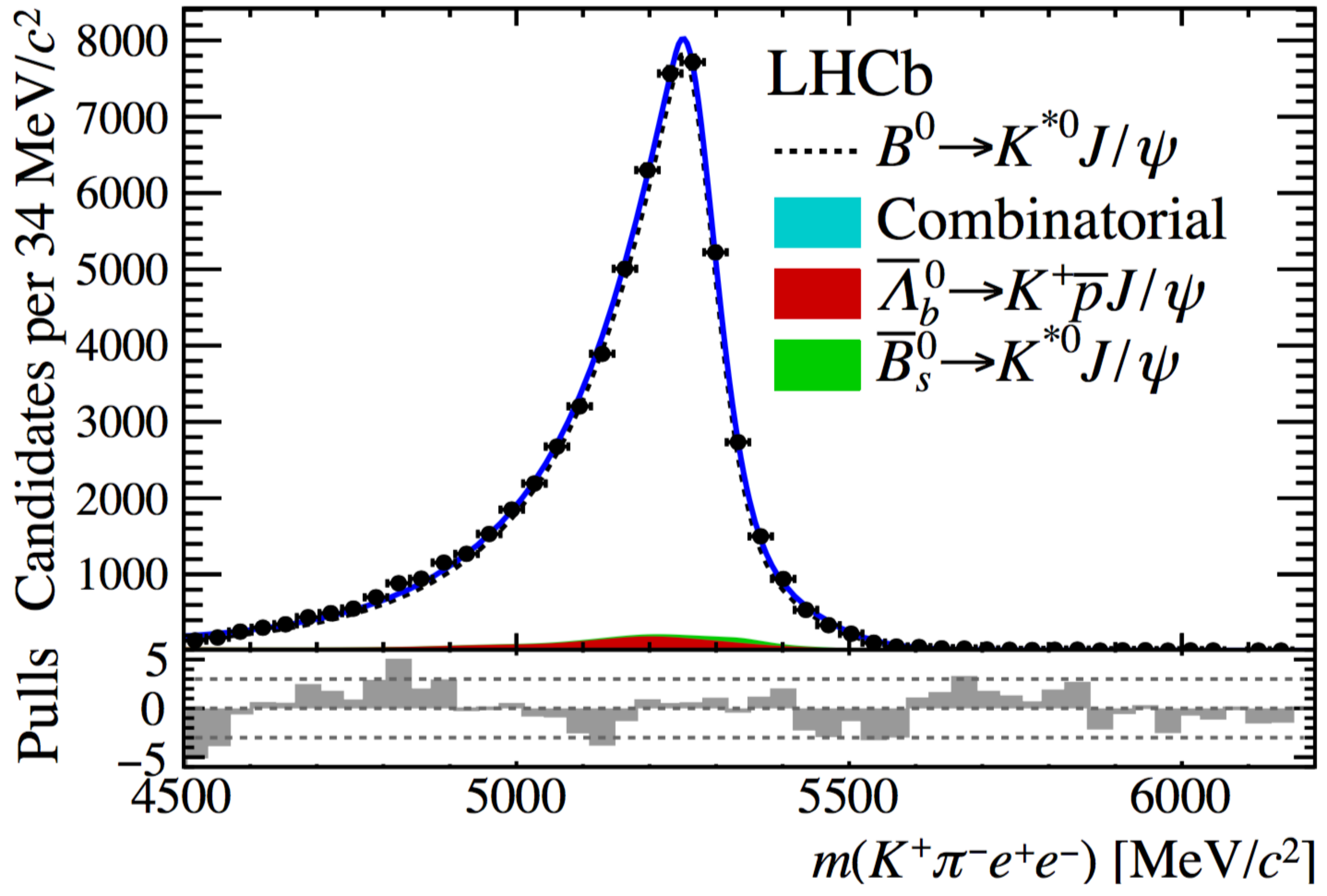
Control of efficiencies tested by measuring J/ψ ratio.

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









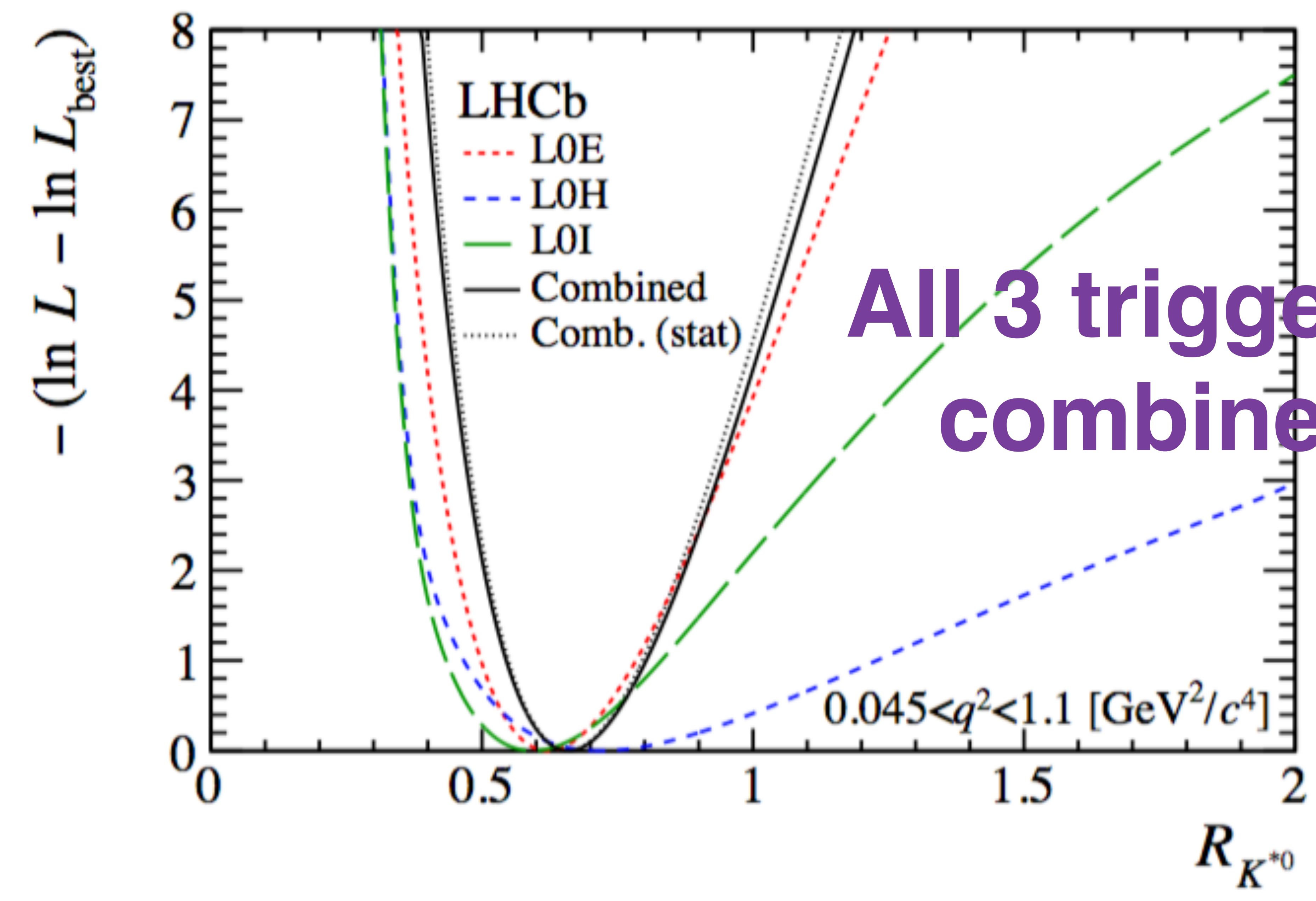
All 3 trigger categories combined in the fit

JHEP 08 (2017) 055

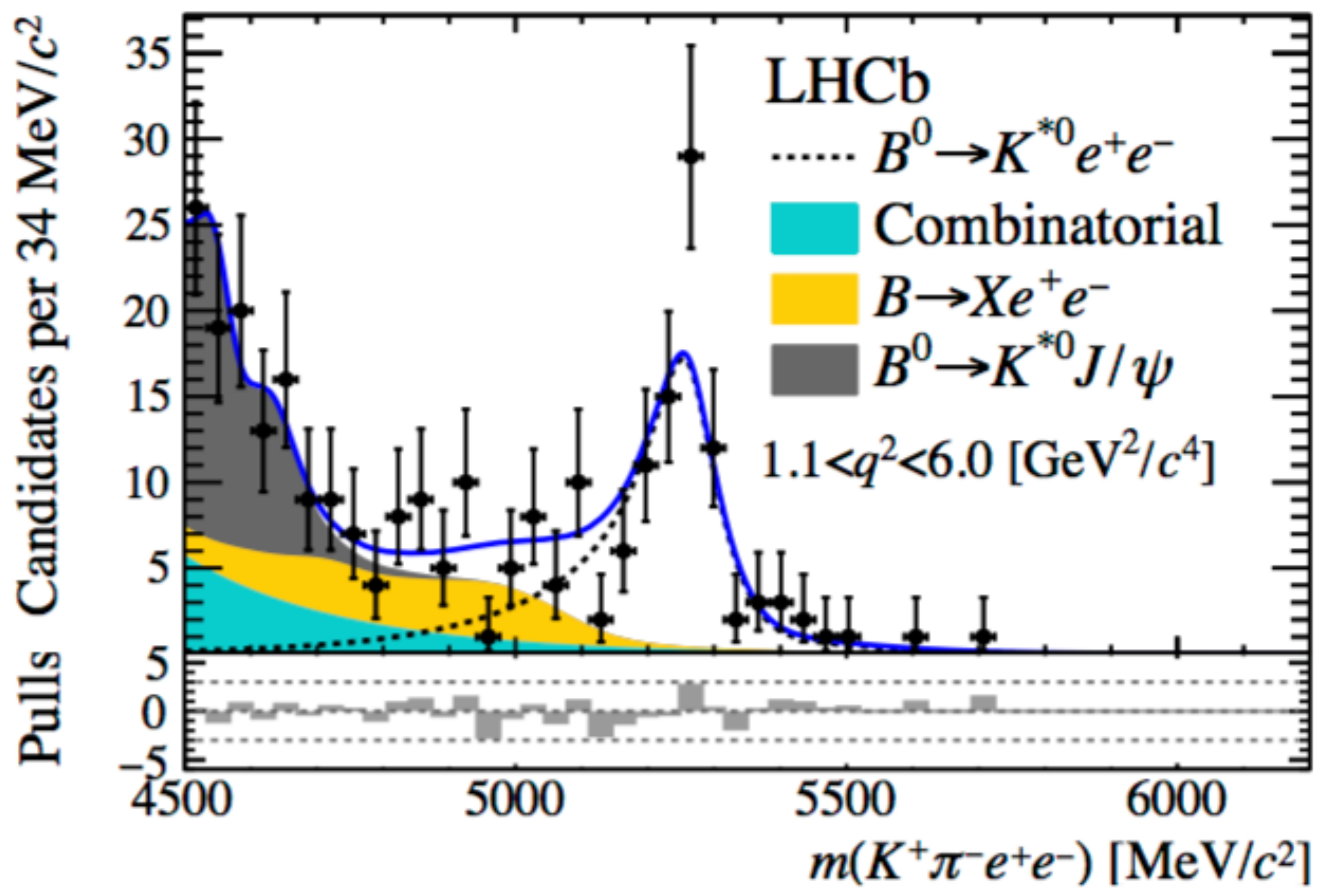
R(K*)

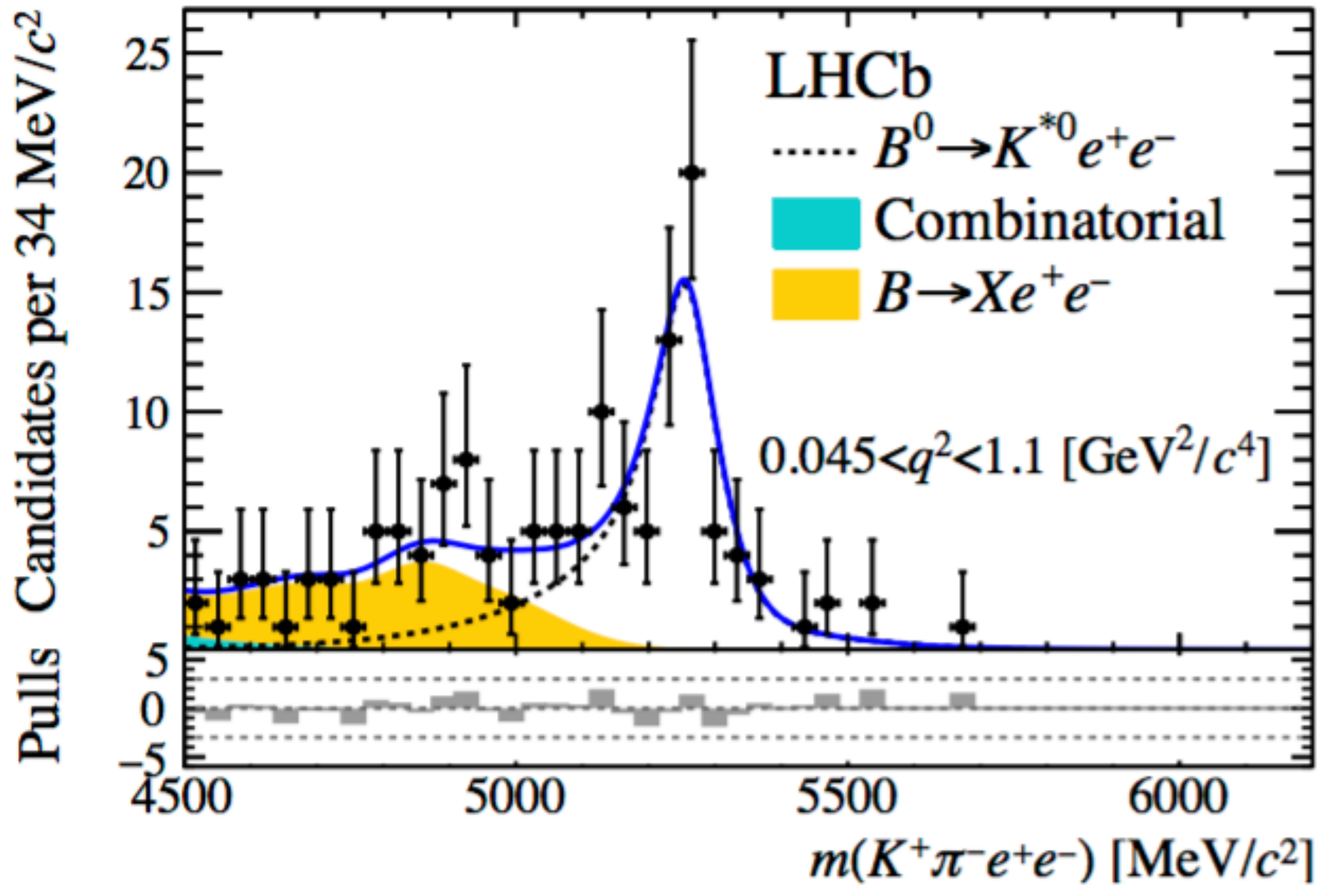
Also using a double ratio method.

Measured in two q^2 regions.



All 3 trigger categories combined in the fit





JHEP 08 (2017) 055

R(K*)

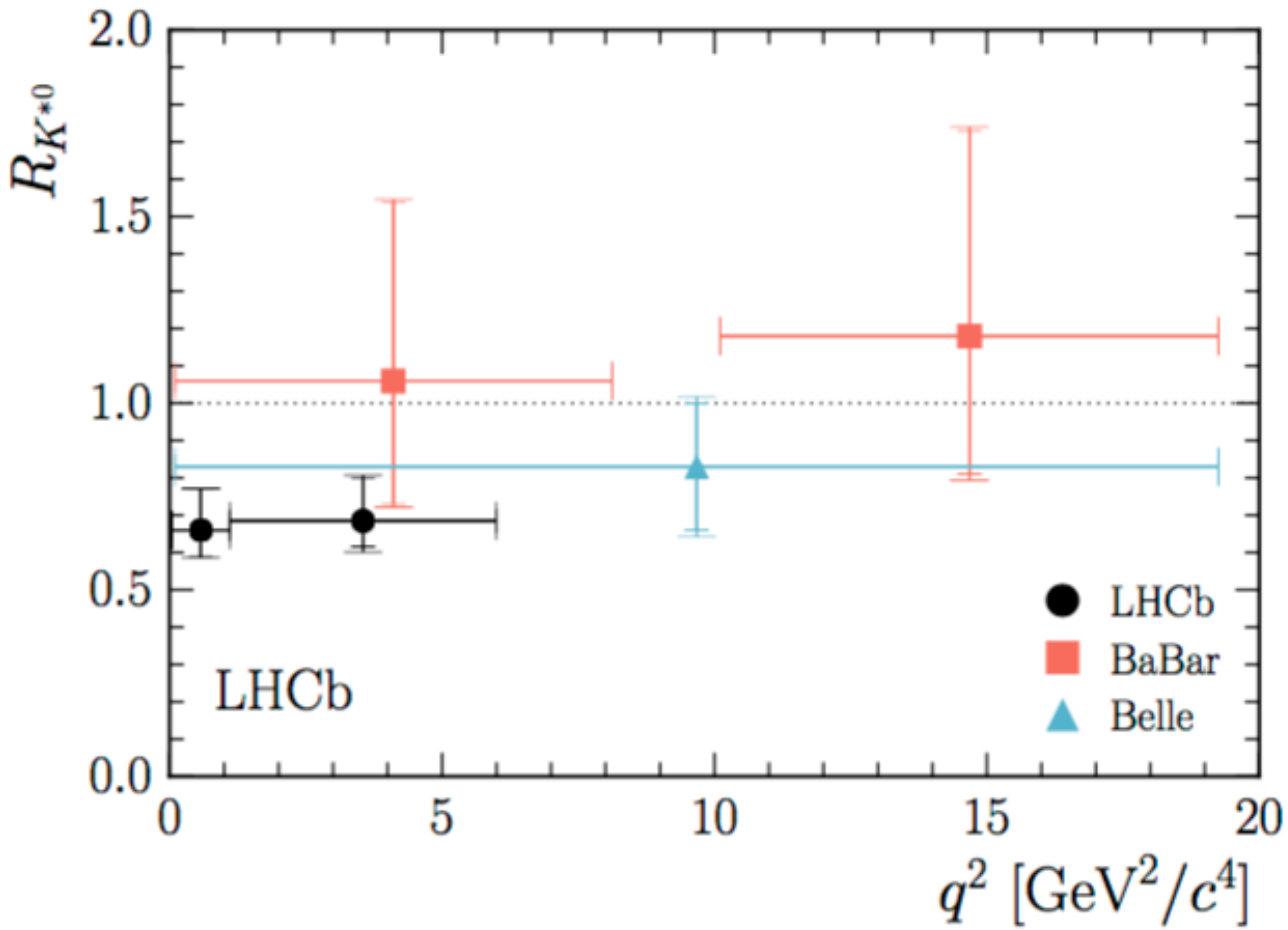
Also using a double ratio method.

Measured in two q² regions.

2.1-2.3σ from SM in the low q² bin

2.4-2.5σ from SM in the central q² bin

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

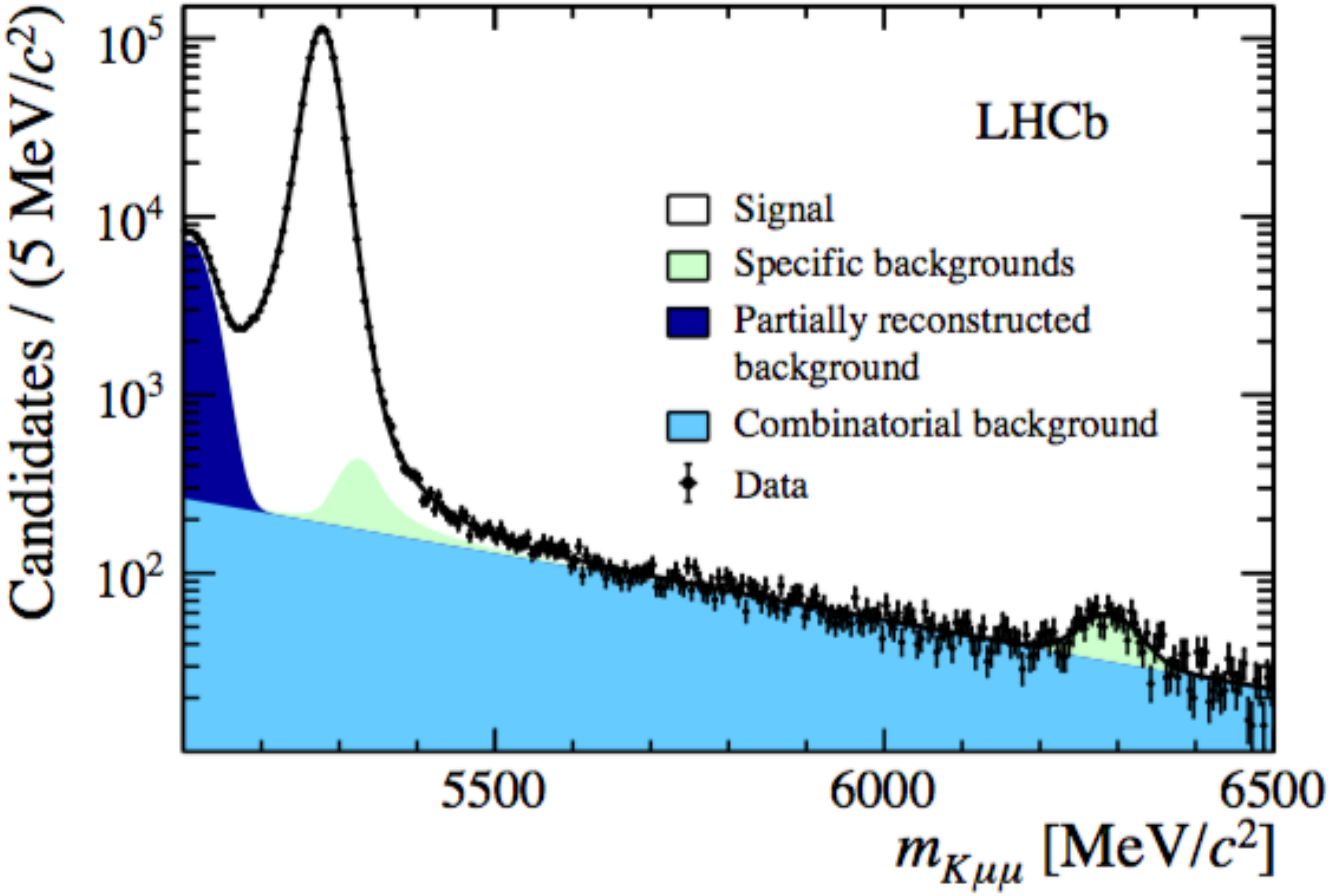


$B^+ \rightarrow K^+\mu^+\mu^-$ Phase Difference

Measurement of phase differences between long and short distance contributions.

Probe whether or not tensions are coming from not well known SM processes.

About 980,000 B decays in the RunI sample.



Eur. Phys. J. C (2017) 77: 161

$B^+ \rightarrow K^+\mu^+\mu^-$ Phase Difference

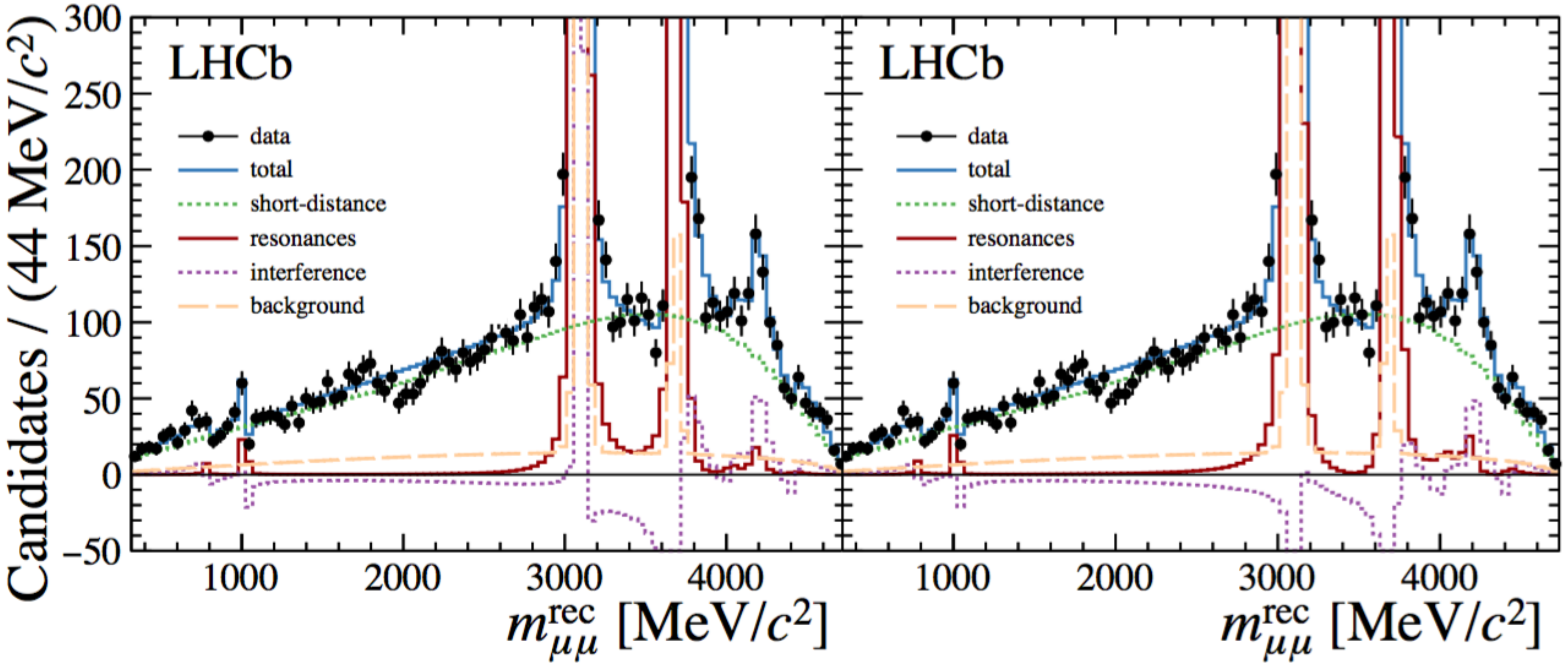
Amplitude described in terms of Wilson Coefficients

Modelling of resonances using relativistic Breit-Wigner

Included in the q^2 fit: ω, ρ^0,ϕ,J/ψ, ψ(2S), ψ(3770), ψ(4040), ψ(4415)

Fit has four solutions, ambiguity on the J/ψ and ψ(2S) phases.

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} = \frac{G_F^2\alpha^2|V_{tb}V_{ts}^*|^2}{128\pi^5}|\boldsymbol{k}|\beta\left\{\frac{2}{3}|\boldsymbol{k}|^2\beta^2\left|\mathcal{C}_{10}f_+(q^2)\right|^2 + \frac{4m_\mu^2(m_B^2-m_K^2)^2}{q^2m_B^2}\left|\mathcal{C}_{10}f_0(q^2)\right|^2 + |\boldsymbol{k}|^2\left[1-\frac{1}{3}\beta^2\right]\left|\mathcal{C}_9f_+(q^2)+2\mathcal{C}_7\frac{m_b+m_s}{m_B+m_K}f_T(q^2)\right|^2\right\},$$



c_7 constrained to SM value

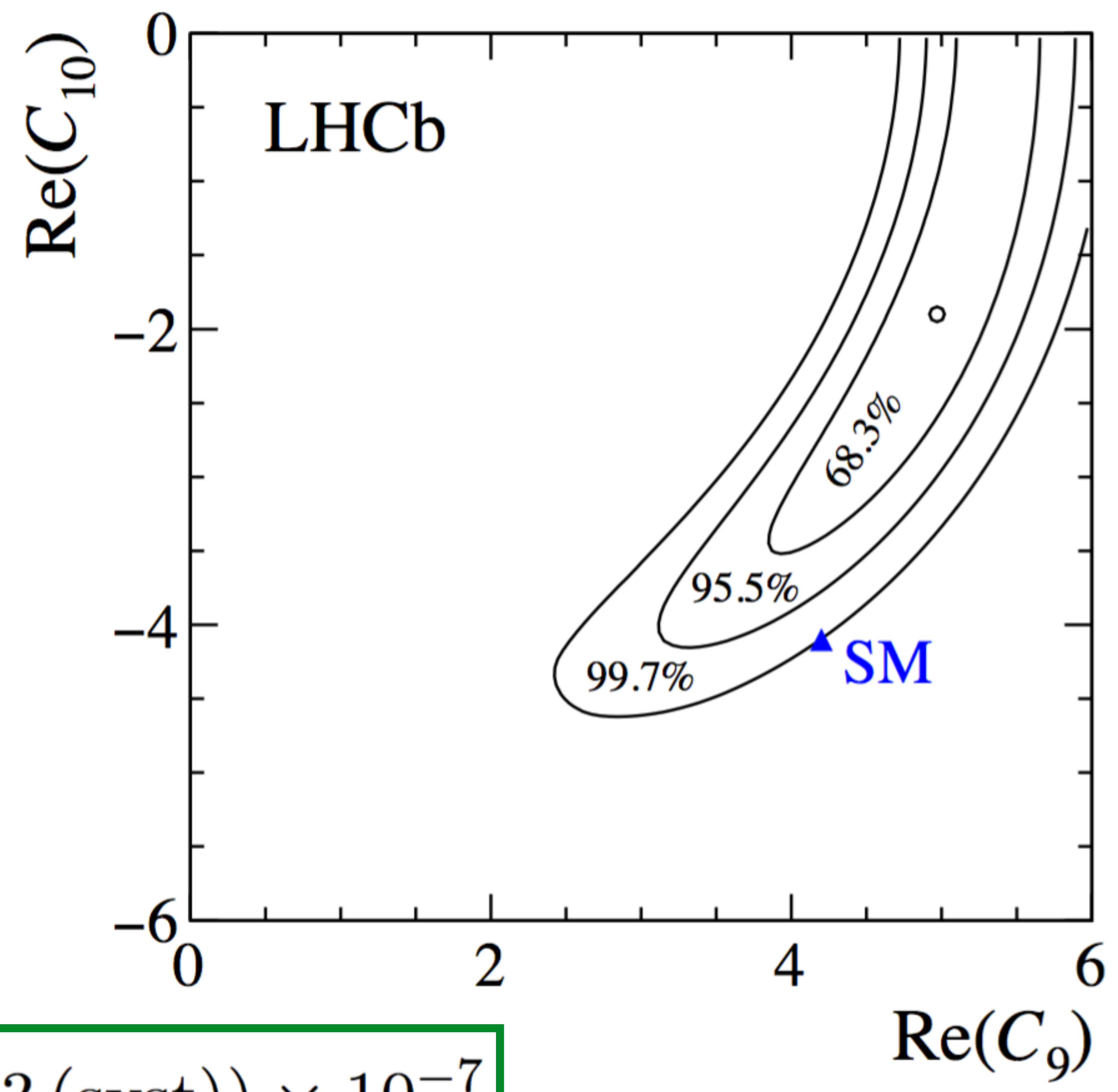
Eur. Phys. J. C (2017) 77: 161

$B^+ \rightarrow K^+\mu^+\mu^-$ Phase Difference

Amplitude described in terms of Wilson Coefficients

Assuming coefficients to be real.

Dominant uncertainty arises form B → K Hadronic form factors.



$$\mathcal{B}(B^+ \to K^+\mu^+\mu^-) = (4.37 \pm 0.15\,(\text{stat}) \pm 0.23\,(\text{syst})) \times 10^{-7}$$

Eur. Phys. J. C (2017) 77: 161

Conclusion

Very interesting set of anomalies observed in b-hadron decays.

LHCb has been able to probe very rare $b \to s\, ll$ and challenging $b \to c l \nu$ transitions.

LHCb will update all presented analysis with Run 2 data.

Other decays, such as $\Lambda_b \to pk\, ll$, $B \to \phi ll$ are being investigated.

Backup

R(J/psi) SM predictions

Phys. Lett. B 452, 129 (1999)

arXiv:hep-ph/0211021

Phys. Rev. D 73, 054024 (2006)

Phys. Rev. D 74, 074008 (2006)