Rare leptonic and semi-leptonic decays at LHCb

Tom Hadavizadeh
On behalf of the LHCb collaboration

58th Rencontres de Moriond 2024
QCD and High Energy Interactions

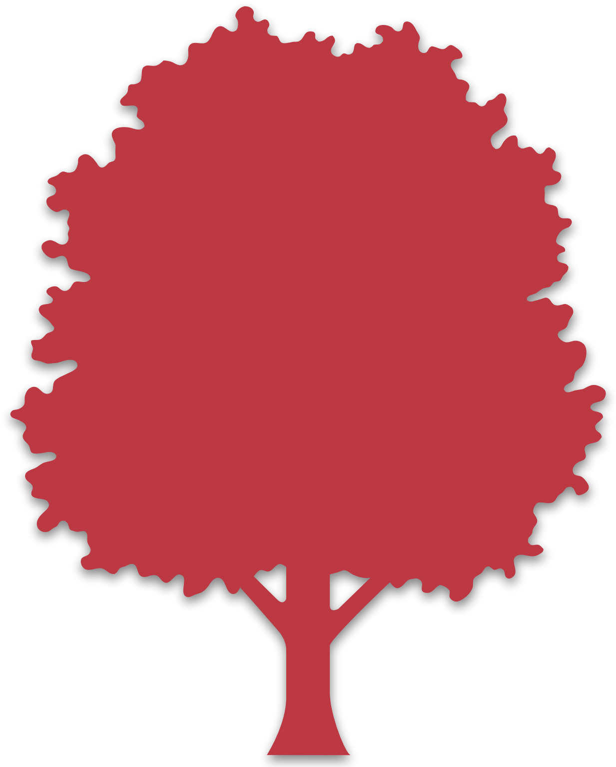
2nd April 2024

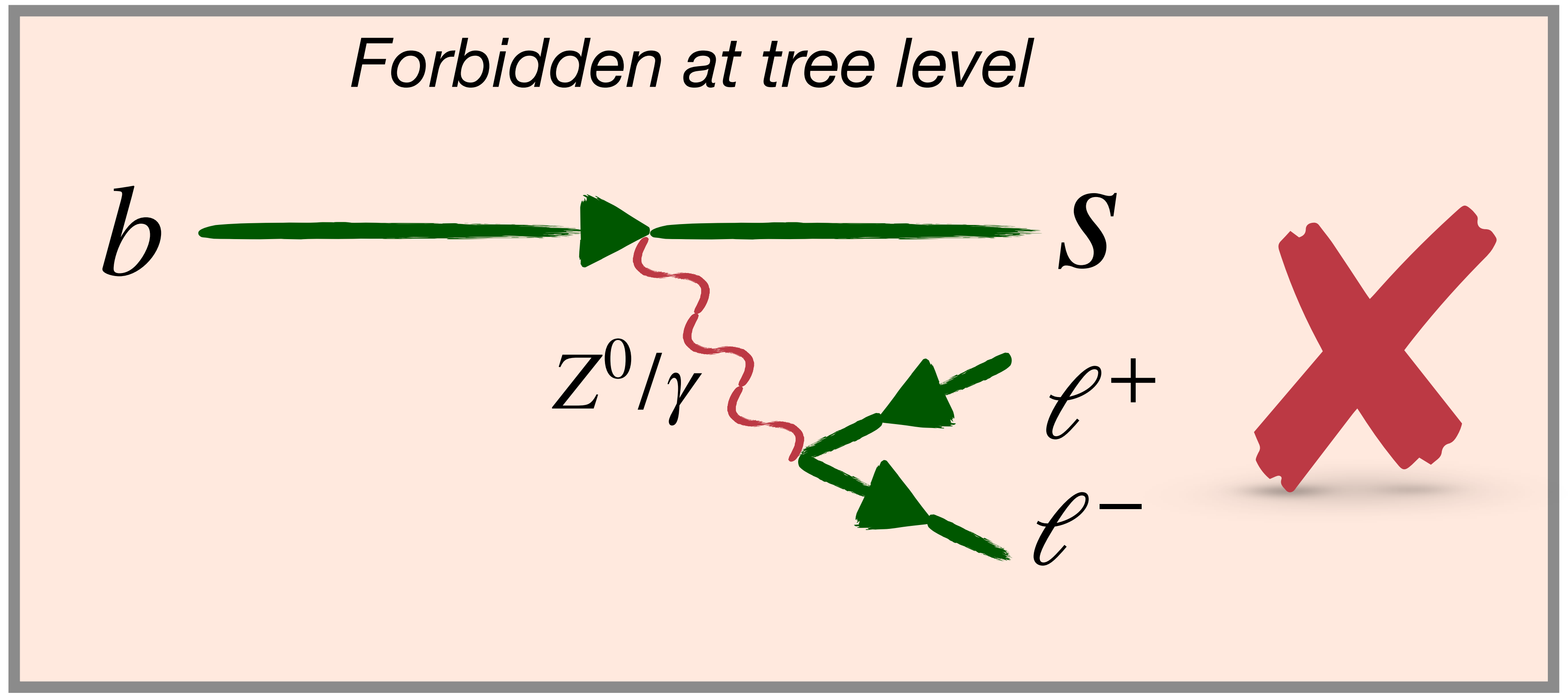
Motivation

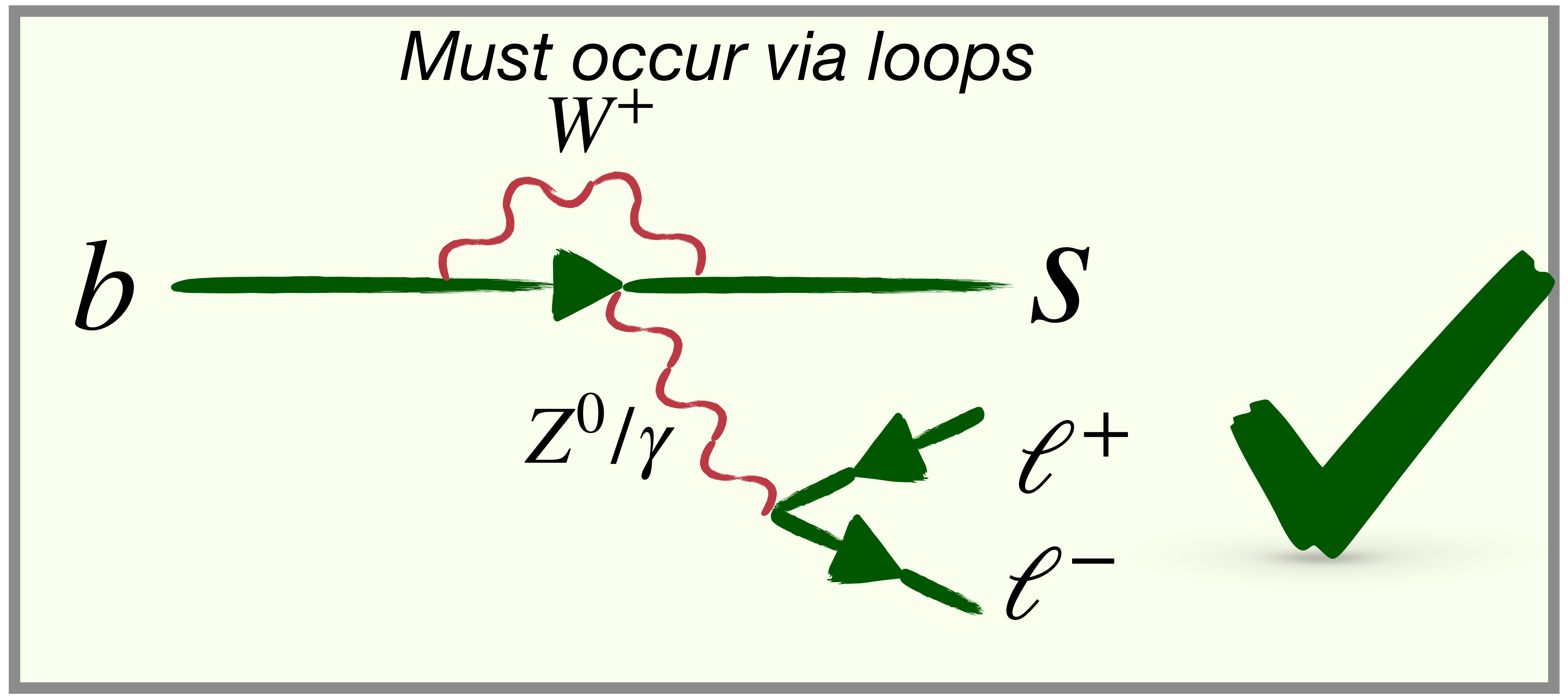
Rare decays are a great place to test the Standard Model

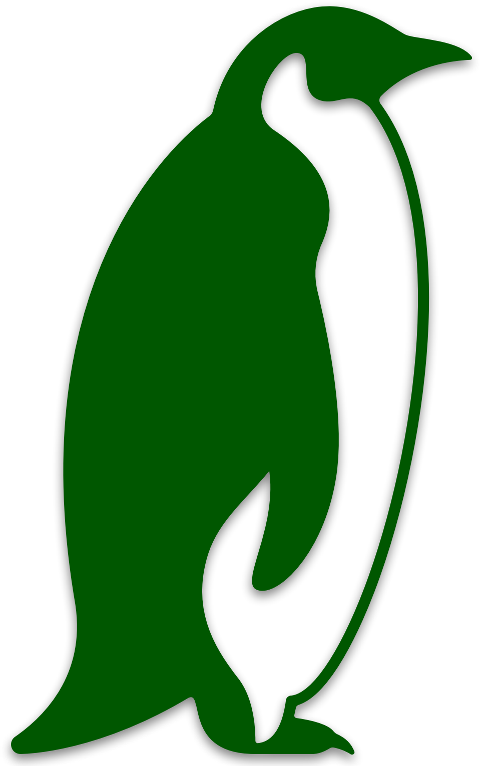
Suppressed in the Standard Model → New physics can be competitive

Flavour changing neutral currents are particularly sensitive area e.g. $b \to s\ell\ell$







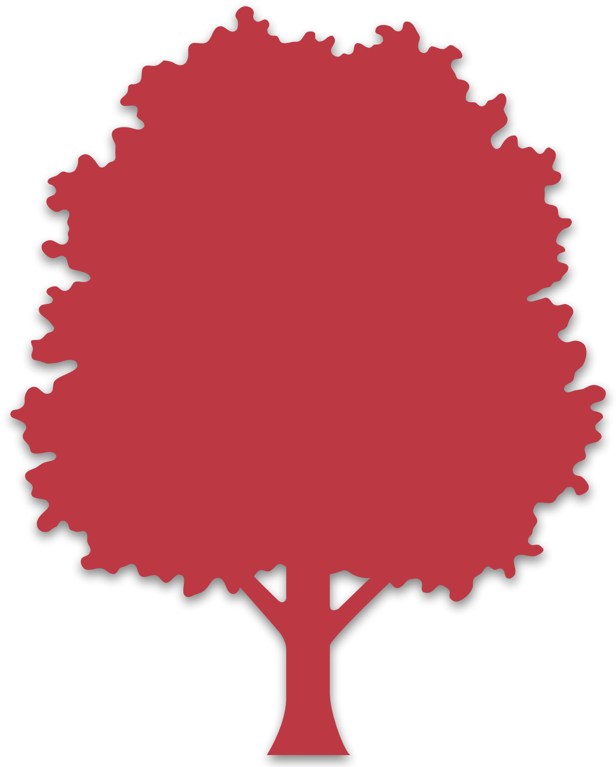


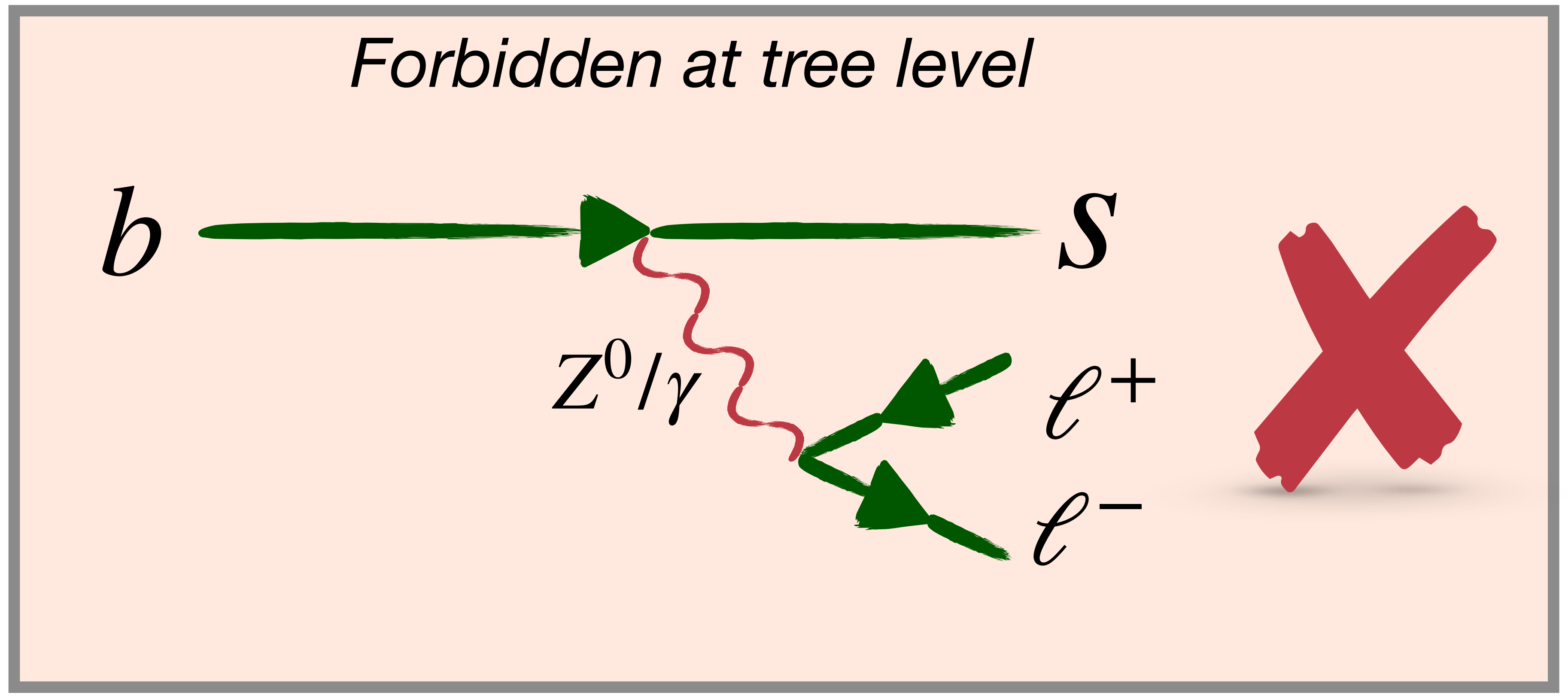
Motivation

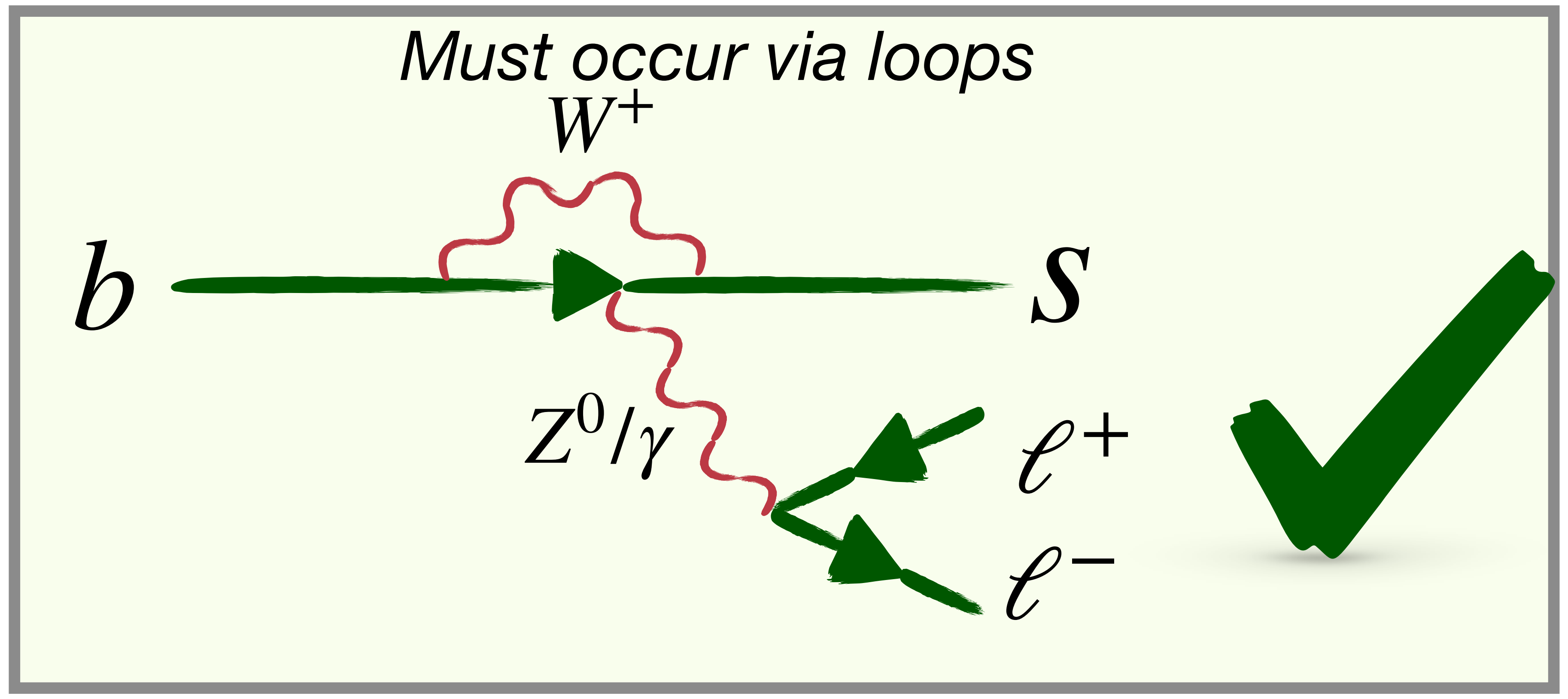
Rare decays are a great place to test the Standard Model

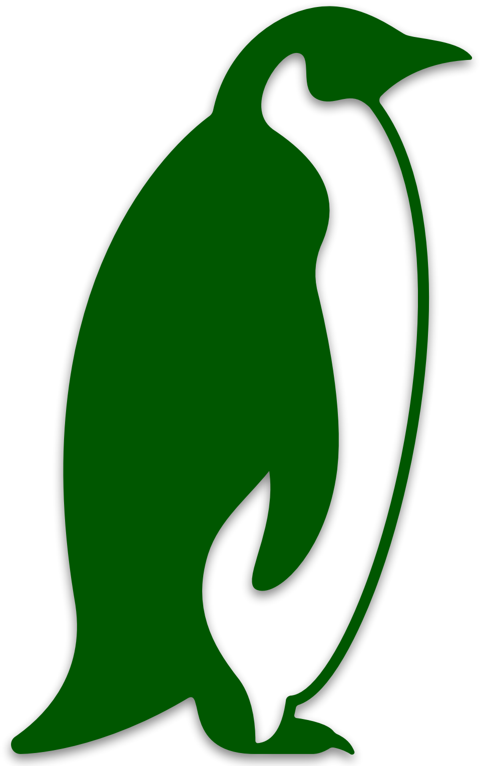
Suppressed in the Standard Model → New physics can be competitive

Flavour changing neutral currents are particularly sensitive area e.g. $b \to s\ell\ell$

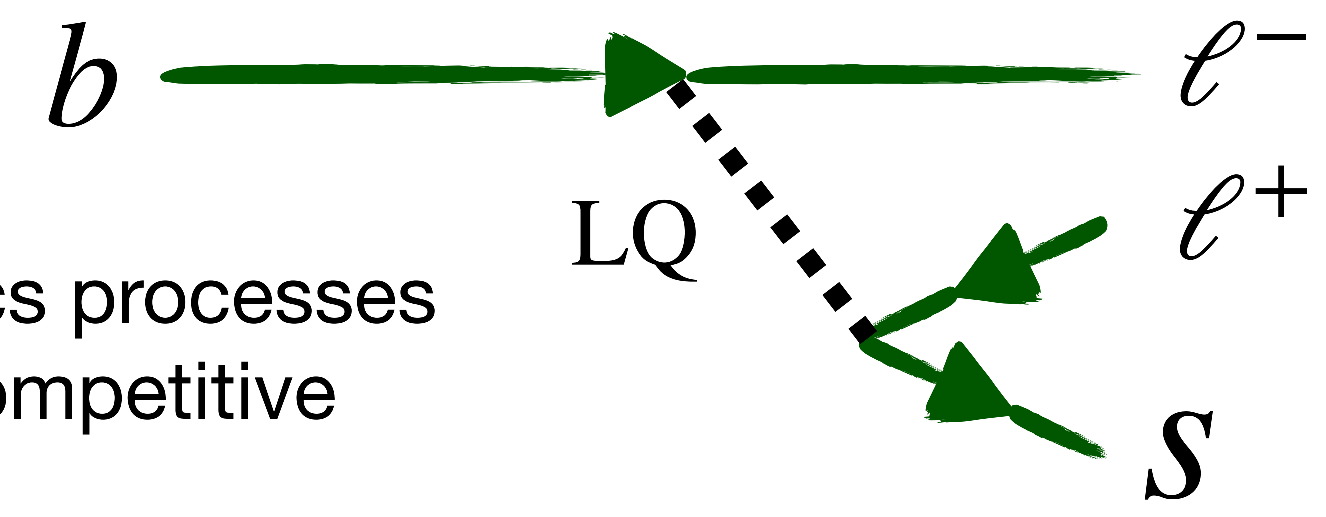








New Physics processes could be competitive



?

Rare decays at LHCb

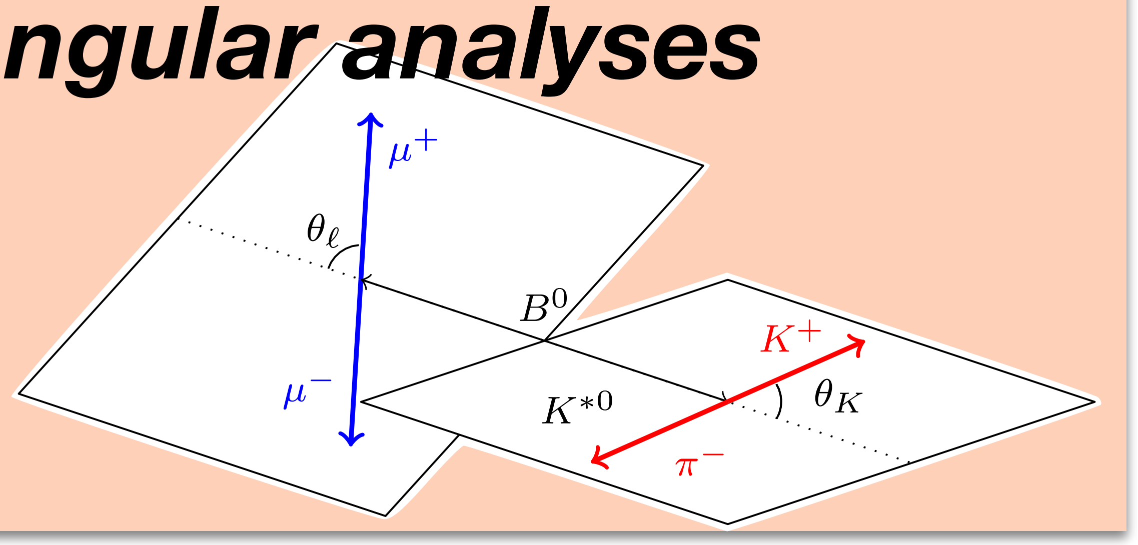
Rare decays can provide a wealth of information

Branching fractions

$$\frac{d\Gamma(B^+ \to K^+\mu^+\mu^-)}{dq^2}$$

Angular analyses

$$P_5'$$



Lepton flavour universality tests

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

← Experimentally more straight forward

Precise theory predictions →

Rare decays at LHCb

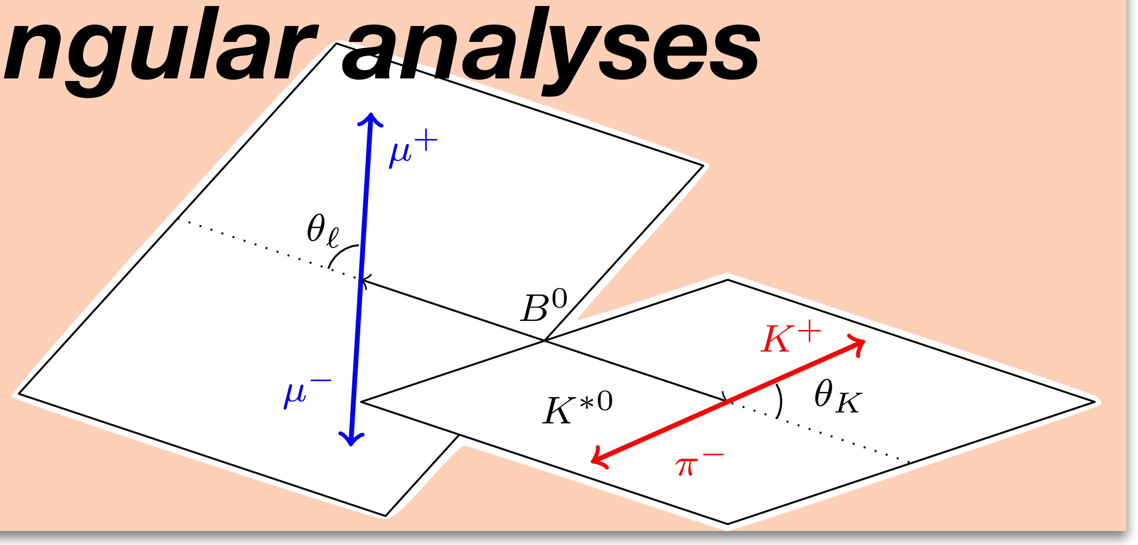
Rare decays can provide a wealth of information

Branching fractions

$$\frac{d\Gamma(B^+ \to K^+\mu^+\mu^-)}{dq^2}$$

Angular analyses

P_5'

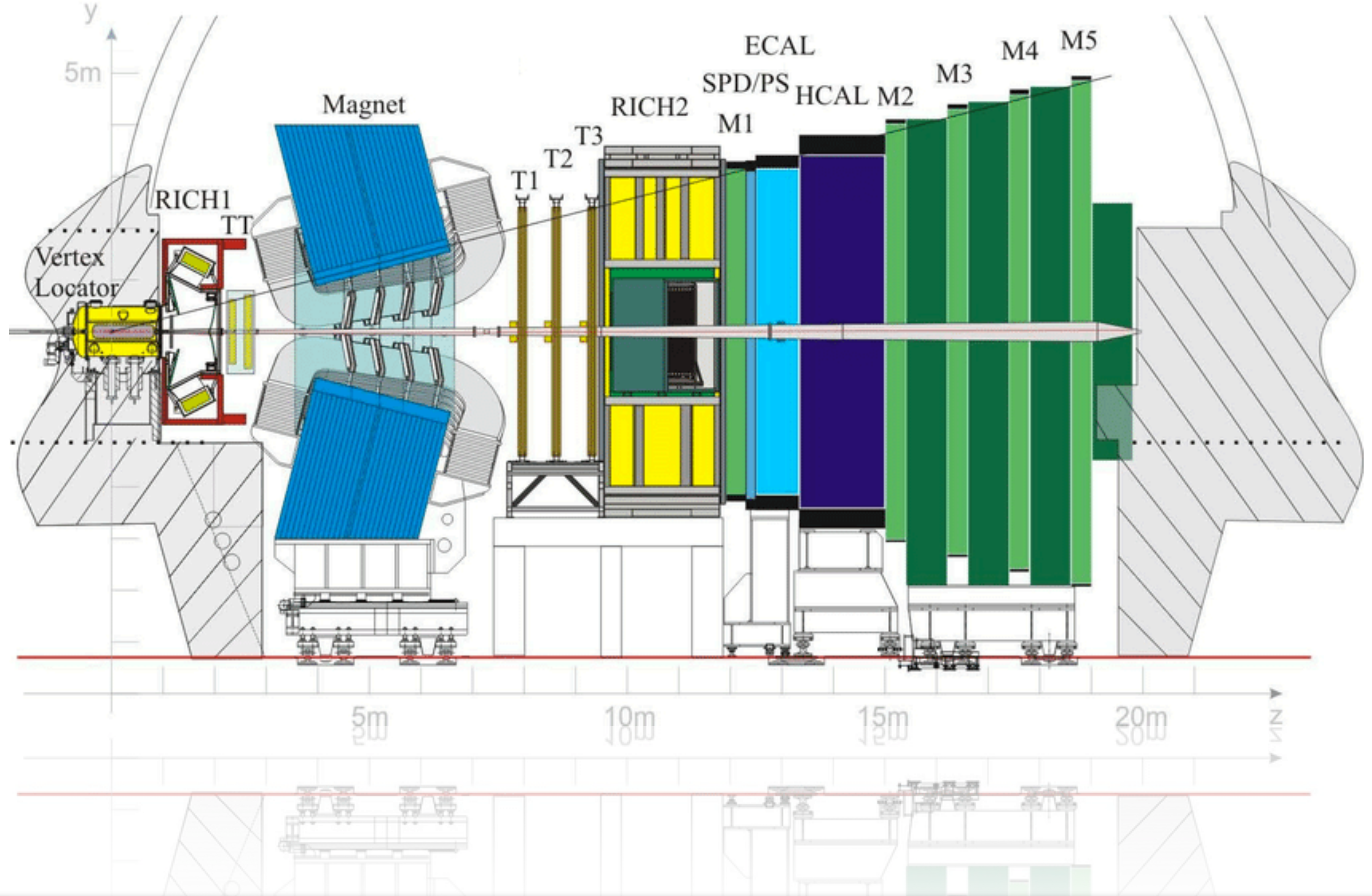


Lepton flavour universality tests

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

← Experimentally more straight forward

Precise theory predictions →



LHCb is an excellent place to study rare processes

- **Precise** tracking
- **Efficient** hadron and lepton PID
- **Large samples** of b and c-hadrons collected in Run1 + Run2

Today's outline

Shown for the first time ever!

Rare leptonic decay

Run 2

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$

LHCb-CONF-2024-001,
Observation of the rare decay
$J/\psi \to \mu^+\mu^-\mu^+\mu^-$

Shown for the first time ever!

Rare semileptonic decay

Run 1 + Run 2

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

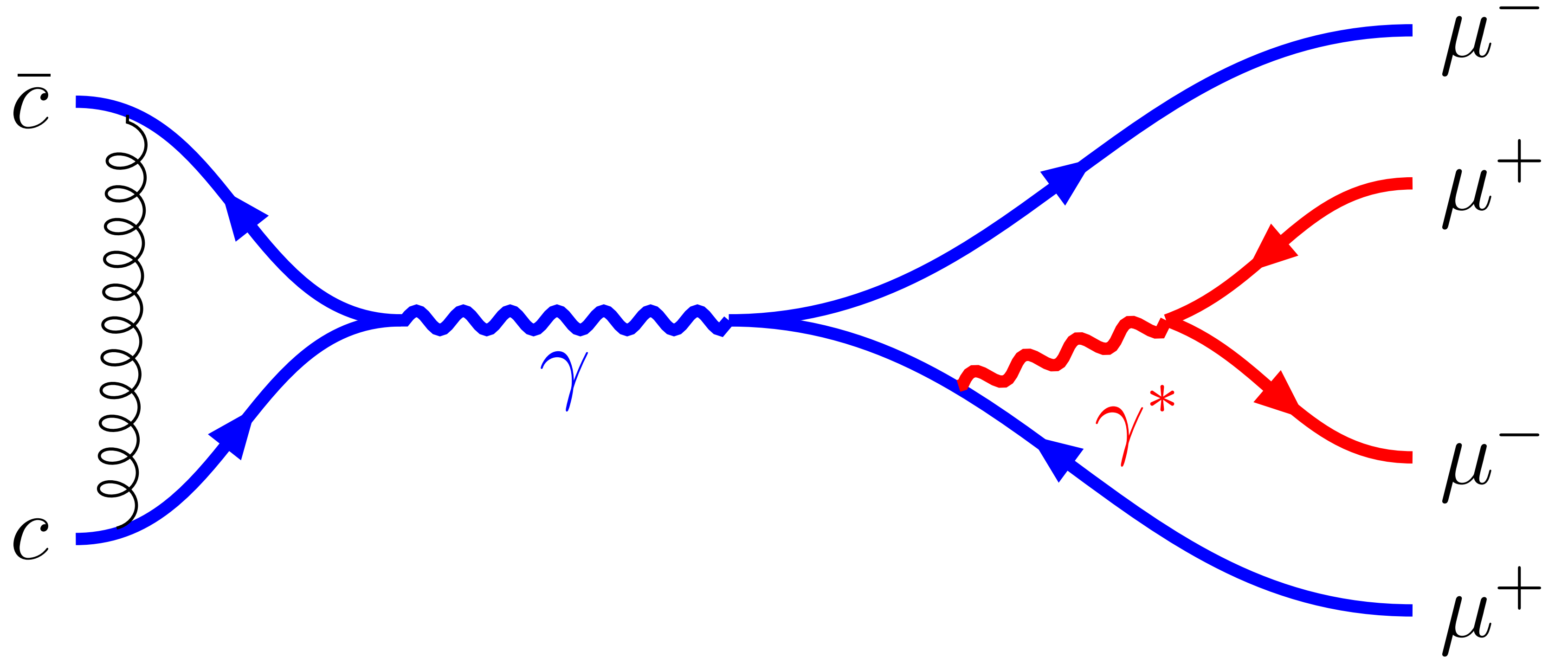
LHCb-PAPER-2024-011, *in preparation*
Comprehensive analysis of local and nonlocal amplitudes in the $B^0 \to K^{*0}\mu^+\mu^-$ decay

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$

Electromagnetic process that proceeds though final-state radiation of a virtual photon

Four lepton decays of heavy quarks are not well studied

Similarity to FCNC processes make this measurement very useful for understanding FSR e.g $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$



Precise SM prediction:

$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (9.74 \pm 0.05) \times 10^{-7}$

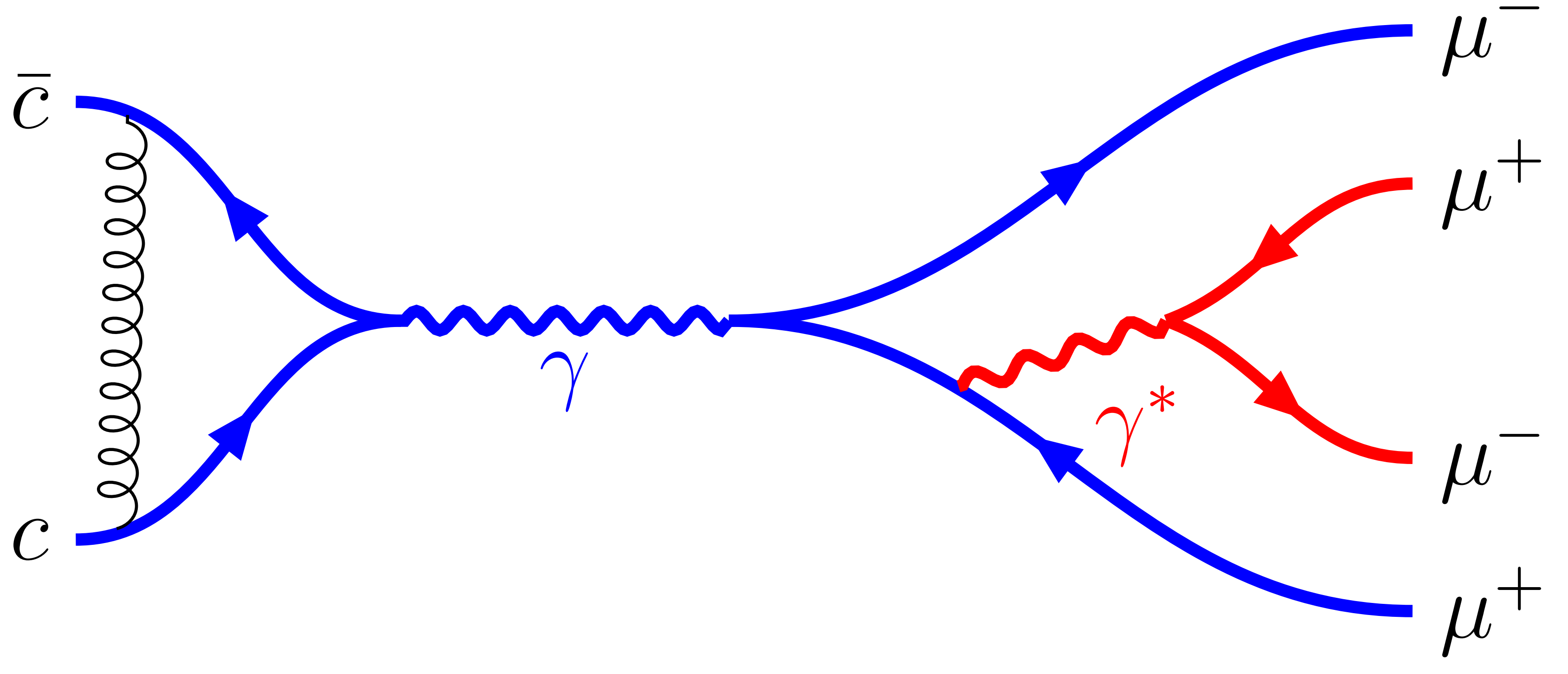
W. Chen et al, [PRD 104 (2021) 9, 094023]

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$

Electromagnetic process that proceeds though final-state radiation of a virtual photon

Four lepton decays of heavy quarks are not well studied

Similarity to FCNC processes make this measurement very useful for understanding FSR e.g $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$



Precise SM prediction:

$$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (9.74 \pm 0.05) \times 10^{-7}$$

W. Chen et al, [PRD 104 (2021) 9, 094023]

The state of play

BESIII

$J/\psi \to e^+e^-e^+e^-$ ✓

$J/\psi \to e^+e^-\mu^+\mu^-$ ✓

$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) < 16 \times 10^{-7}$ ✗

[PRD 109, 052006 (2024)]

CMS

$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (10.1^{+3.3}_{-2.7} \pm 0.4) \times 10^{-7}$ ✓

[arXiv:2403.11352] As of 17th March 2024

Analysis strategy

Measures the branching fraction $\mathscr{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)$ relative to normalisation channel $J/\psi \to \mu^+\mu^-$

$$R_{BR} \equiv \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \to \mu^+\mu^-)}$$

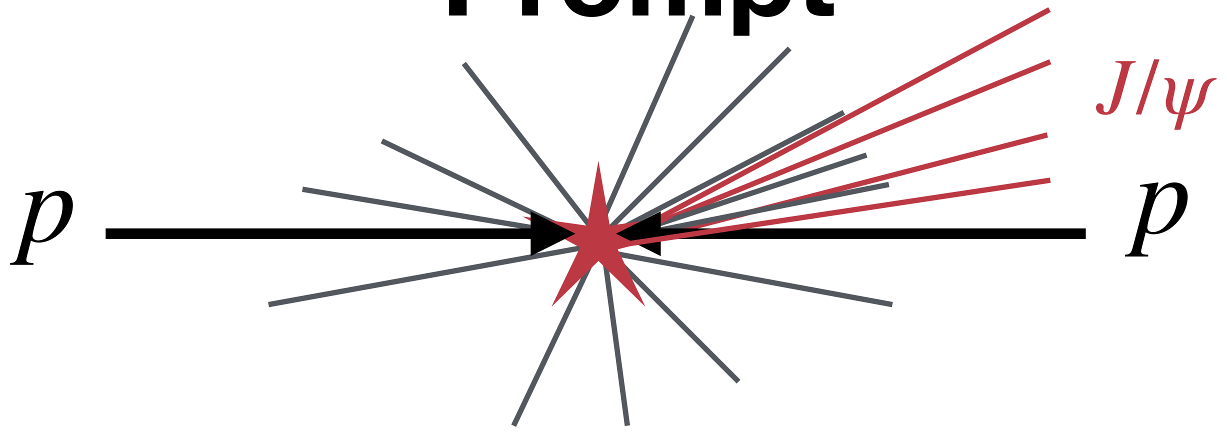
Analysis strategy

Measures the branching fraction $\mathscr{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)$ relative to normalisation channel $J/\psi \to \mu^+\mu^-$

$$R_{BR} \equiv \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(J/\psi \to \mu^+\mu^-)}$$

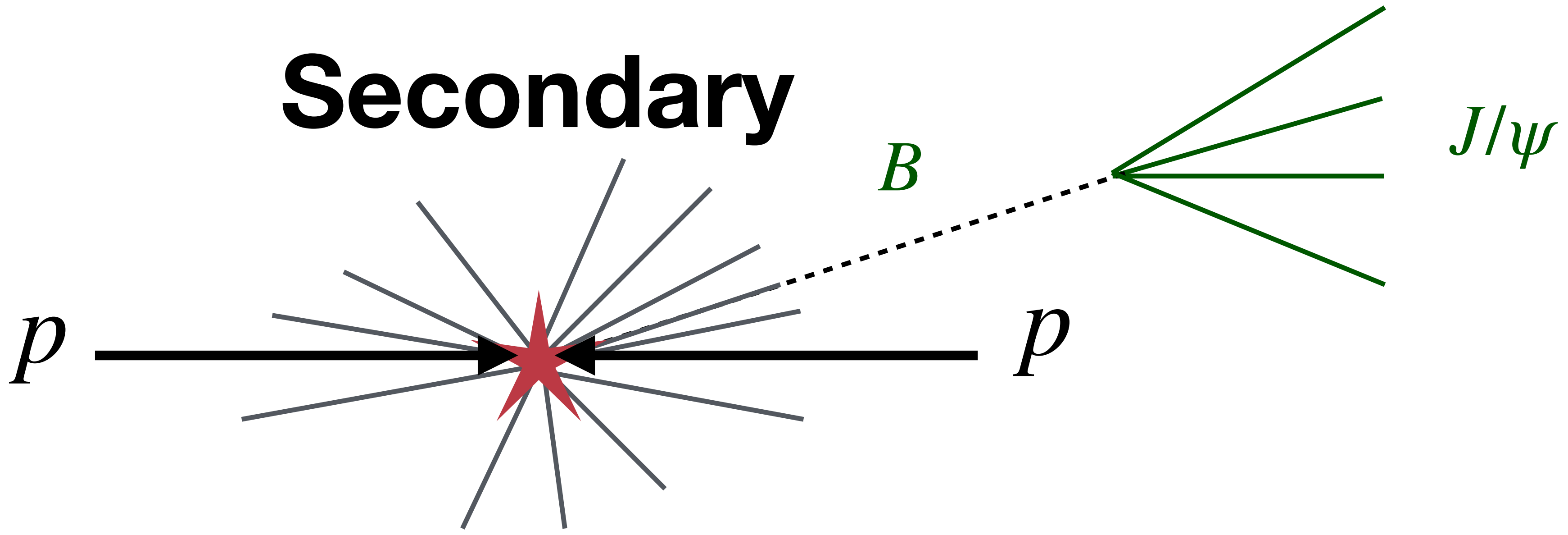
J/ψ from **two origins** are used:

Prompt



- ✓ High production rate
- X High background rates
- X Requires tight selection

Secondary



- X Lower production rate
- ✓ Lower background rates
- ✓ Profit from B decay triggers

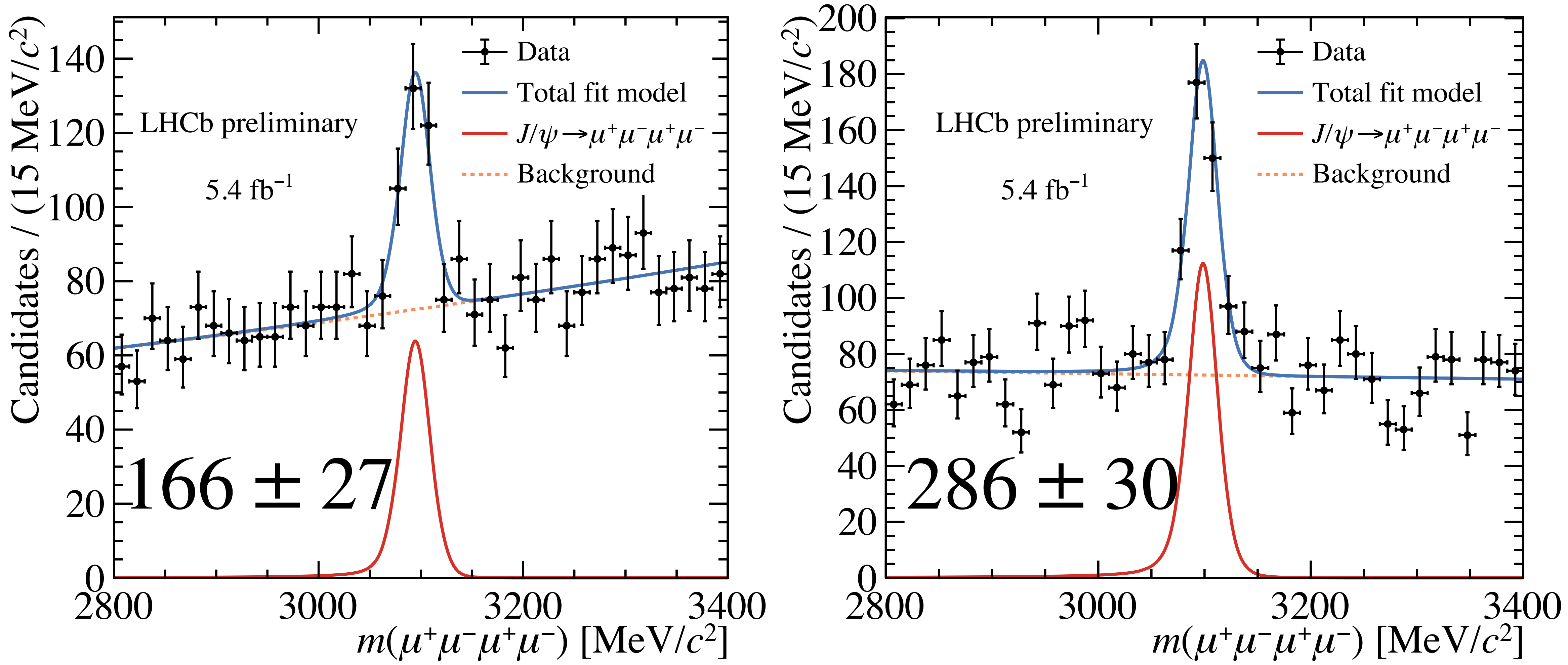
Dedicated **BDT algorithms** are trained to reject combinatorial background

Results

LHCb-CONF-2024-001

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$ is **observed** in both samples with a large significance ($\gg 5\sigma$)

Prompt **Secondary**



Results

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$ is **observed** in both samples with a large significance ($\gg 5\sigma$)

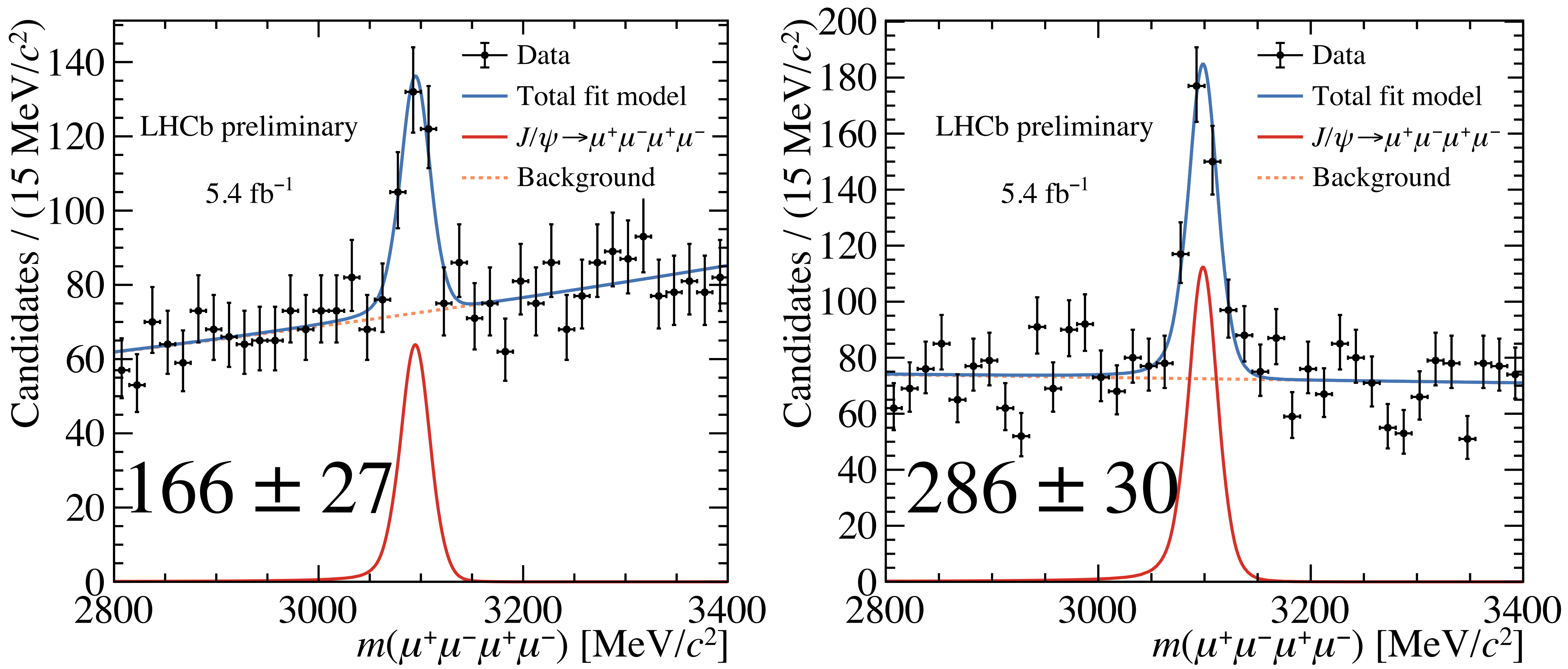
$$R_{BR} = (1.89 \pm 0.17 \pm 0.09) \times 10^{-5}$$

$$\mathscr{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (11.3 \pm 1.0 \pm 0.5 \pm 0.1) \times 10^{-7}$$

Most precise measurement to date

Consistent with SM within 1.4σ

Prompt **Secondary**



Results

$J/\psi \to \mu^+\mu^-\mu^+\mu^-$ is **observed** in both samples with a large significance ($\gg 5\sigma$)

$$R_{BR} = (1.89 \pm 0.17 \pm 0.09) \times 10^{-5}$$

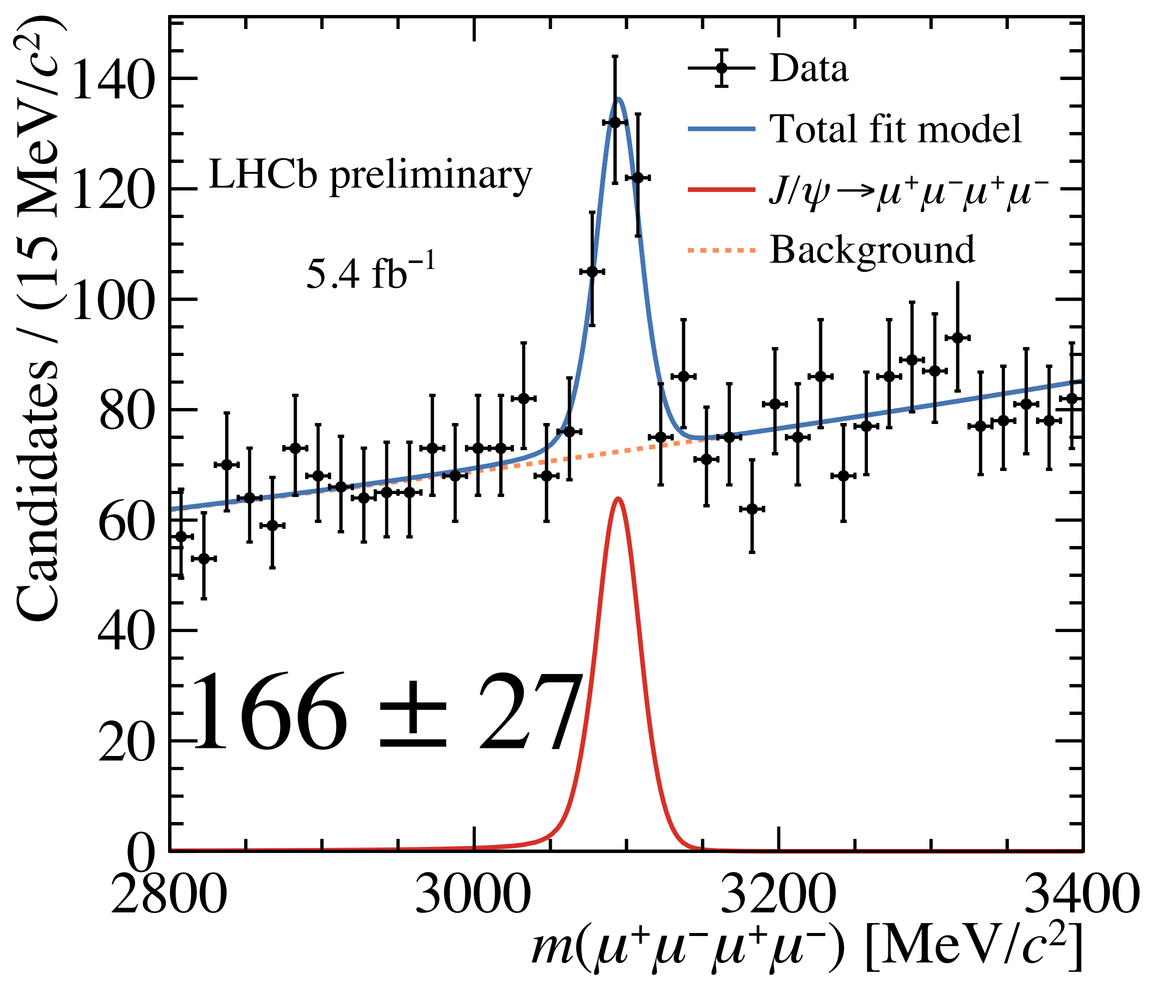
$$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (11.3 \pm 1.0 \pm 0.5 \pm 0.1) \times 10^{-7}$$

Most precise measurement to date

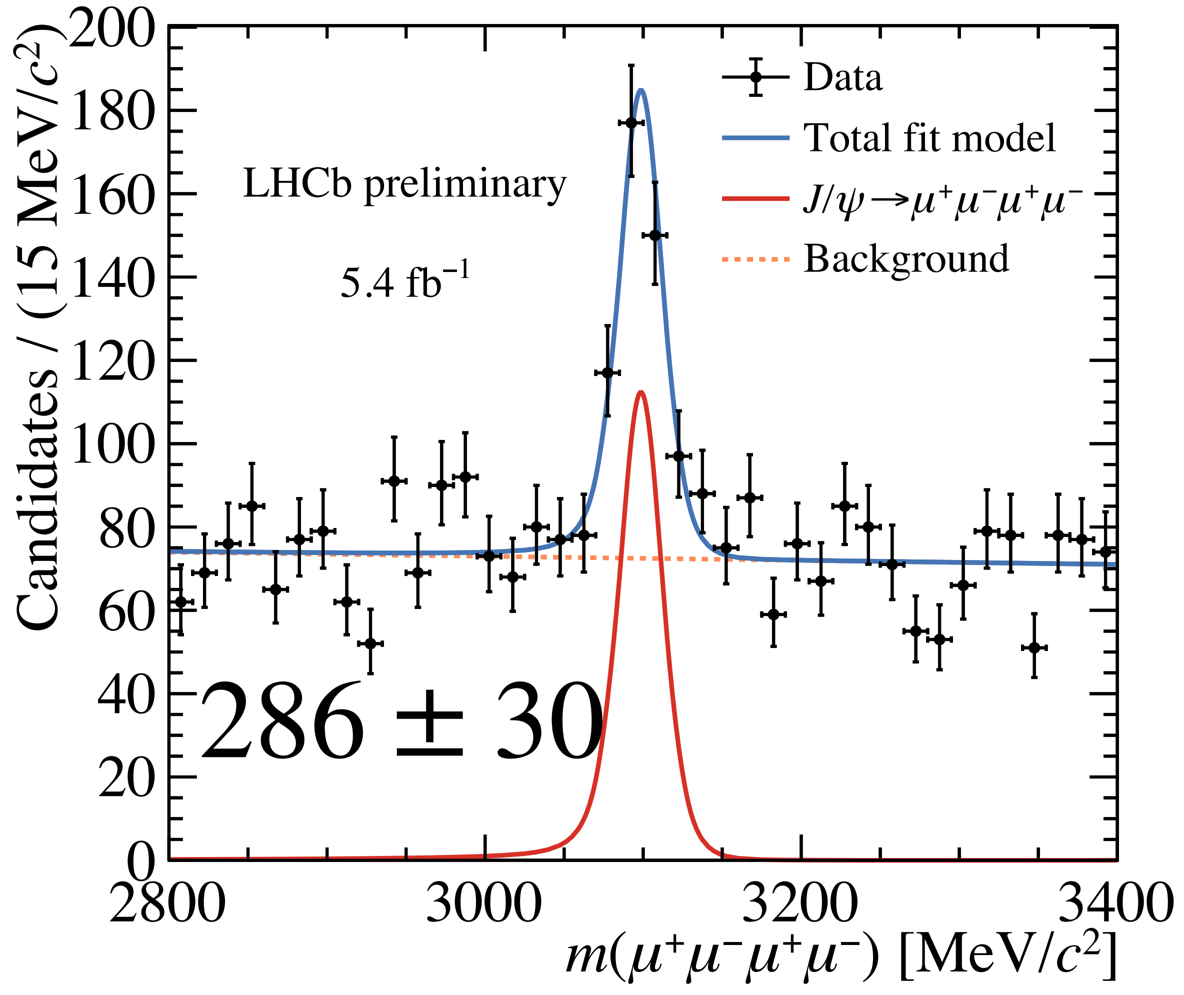
Consistent with SM within 1.4σ

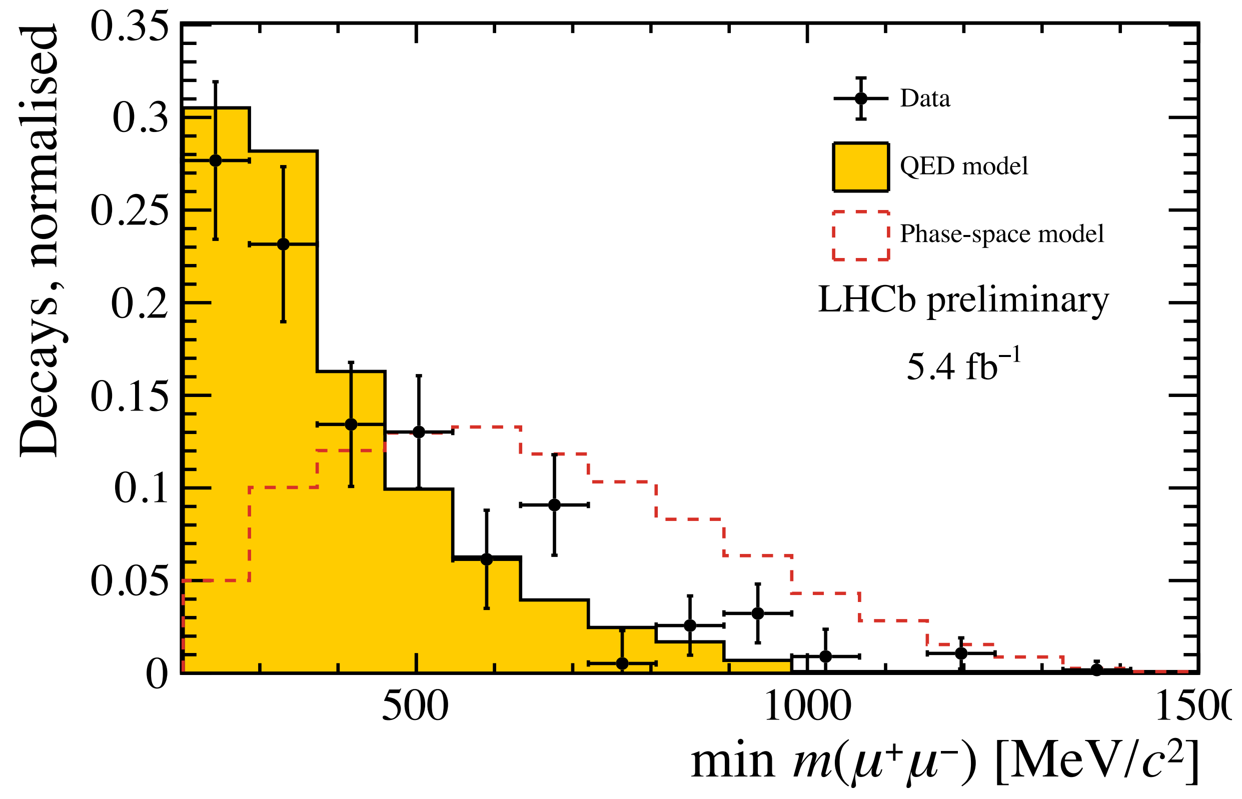
Dimuon mass distributions agree with QED predictions

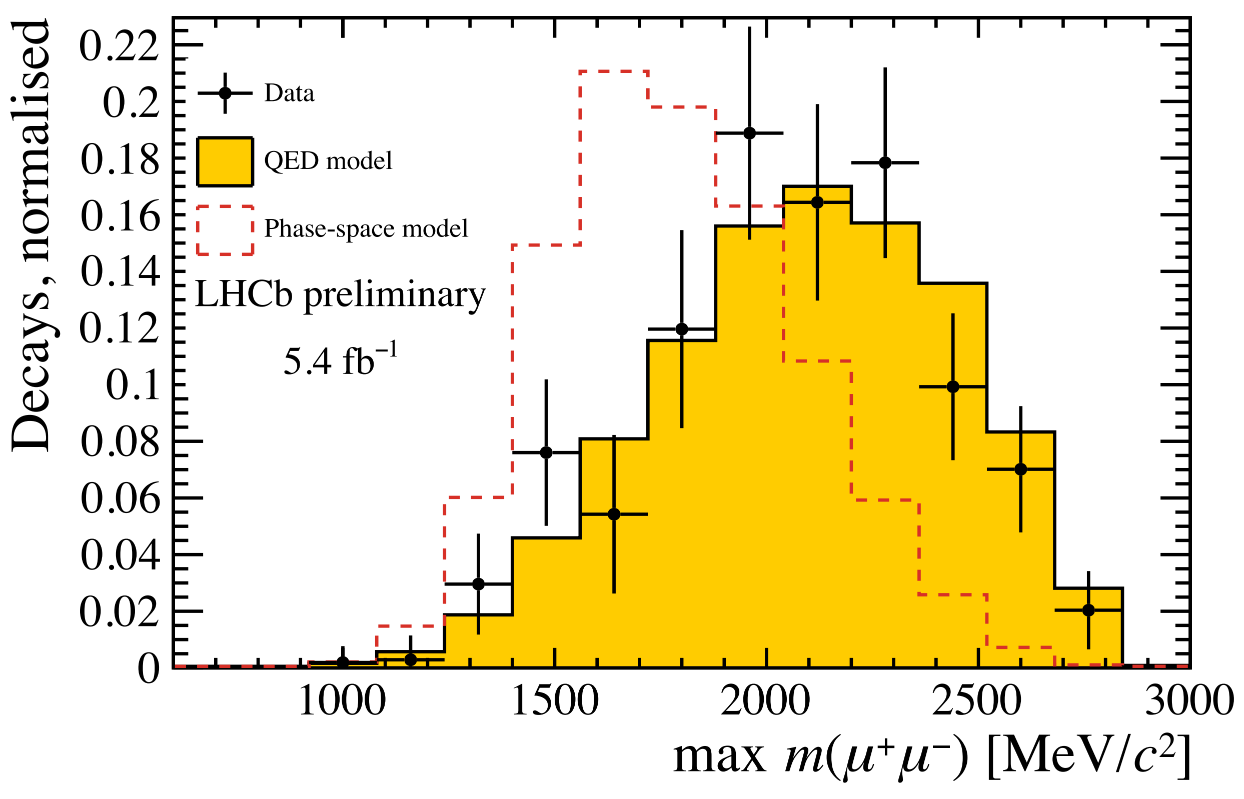
Prompt



Secondary







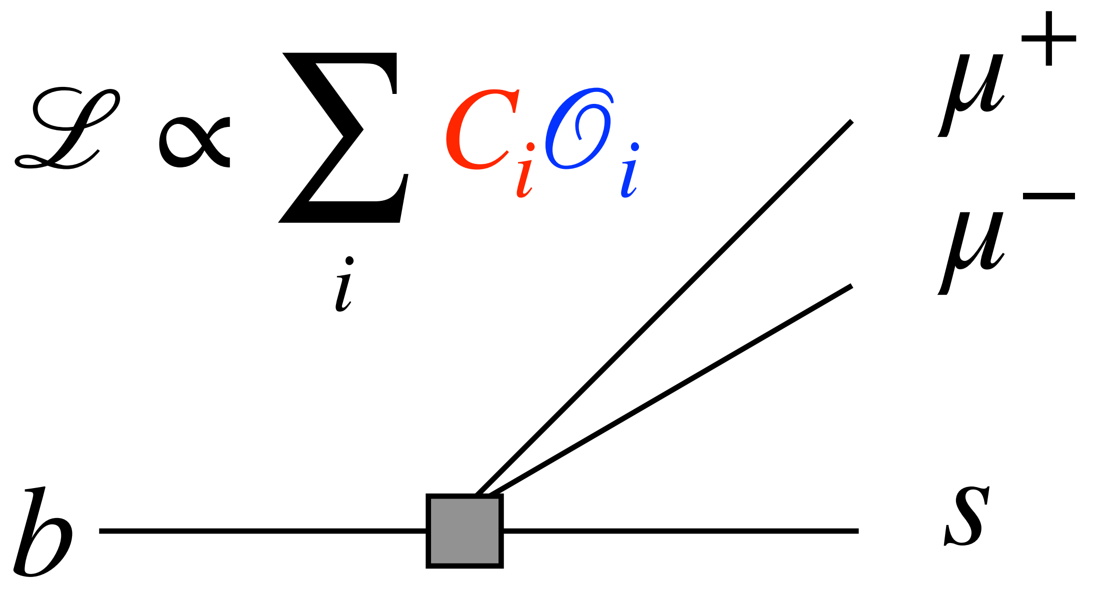
$B^0 \to K^{*0}\mu^+\mu^-$: A very brief history

LHCb-PAPER-2024-011,
in preparation

$B^0 \to K^{*0}\mu^+\mu^-$ has caused lots of interest in the community

$b \to s\mu^+\mu^-$ Weak Effective Theory

$$\mathscr{L} \propto \sum_i C_i \mathcal{O}_i$$



Electromagnetic $C_7^{(\prime)}$

Vector $C_9^{(\prime)}$

Axial vector $C_{10}^{(\prime)}$

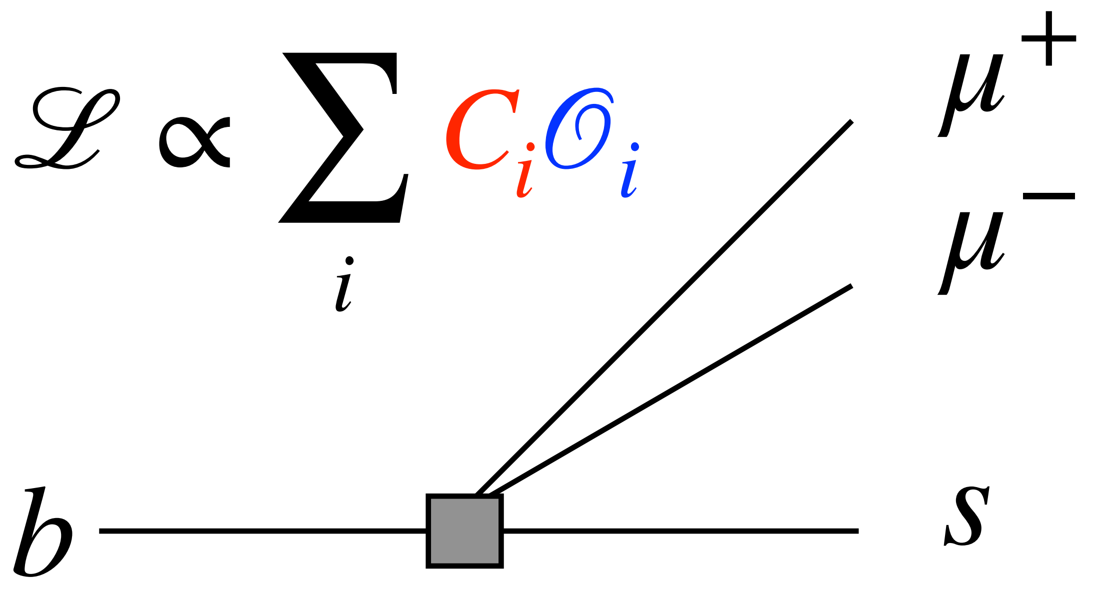
$B^0 \to K^{*0}\mu^+\mu^-$: A very brief history

LHCb-PAPER-2024-011, *in preparation*

$B^0 \to K^{*0}\mu^+\mu^-$ has caused lots of interest in the community

$b \to s\mu^+\mu^-$ Weak Effective Theory

$$\mathscr{L} \propto \sum_i C_i \mathcal{O}_i$$



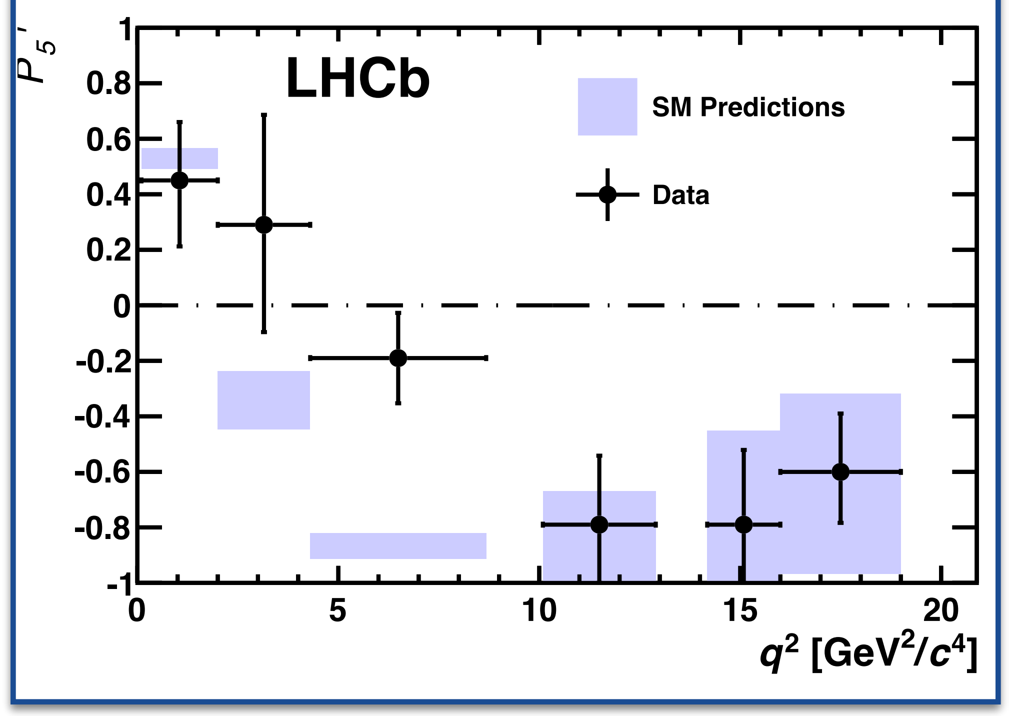
Electromagnetic $C_7^{(\prime)}$

Vector $C_9^{(\prime)}$

Axial vector $C_{10}^{(\prime)}$

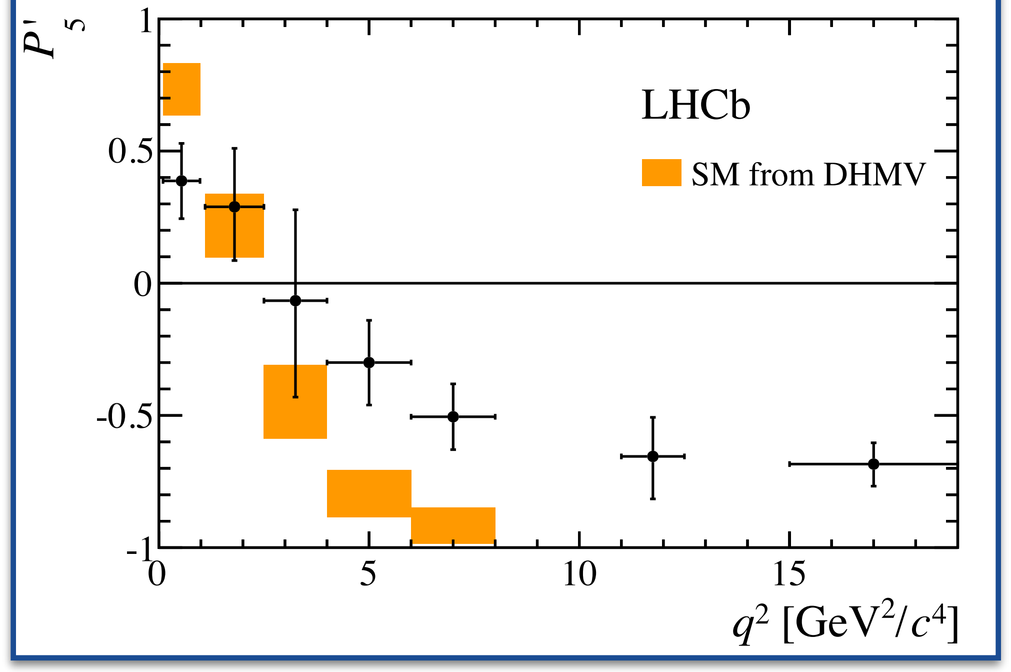
Tensions have remained for ~10 years

2011: $1\ \text{fb}^{-1}$



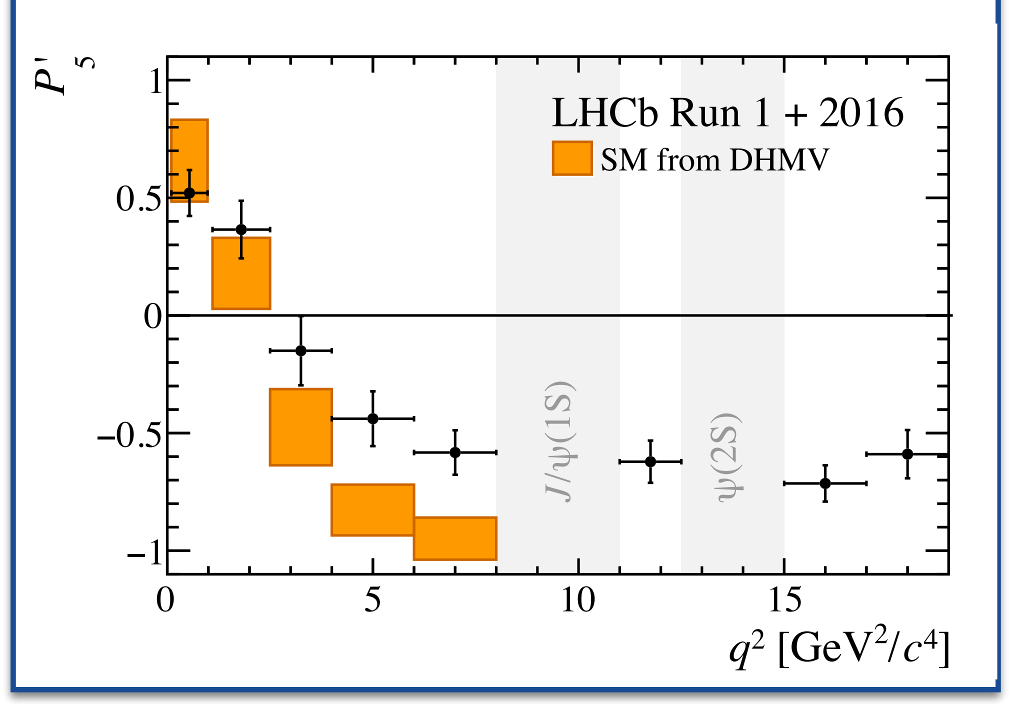
[LHCb-PAPER-2013-037]

Run 1: $3\ \text{fb}^{-1}$



[LHCb-PAPER-2015-051]

Run 1 + 2016: $4.7\ \text{fb}^{-1}$



[LHCb-PAPER-2020-002]

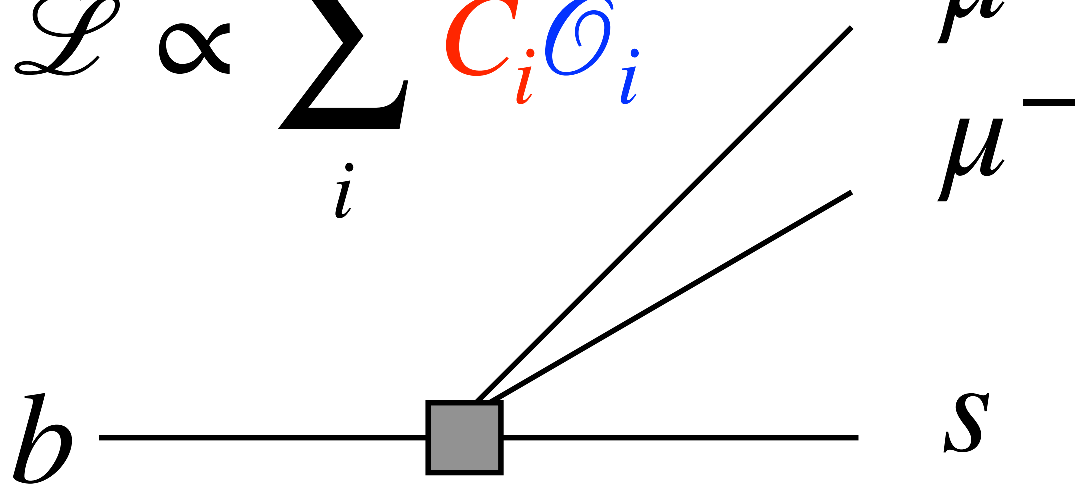
Discrepancies are present in multiple observables and the differential decay rate

$B^0 \to K^{*0}\mu^+\mu^-$: A very brief history

$B^0 \to K^{*0}\mu^+\mu^-$ has caused lots of interest in the community

$b \to s\mu^+\mu^-$ **Weak Effective Theory**

$$\mathscr{L} \propto \sum_i C_i \mathcal{O}_i$$



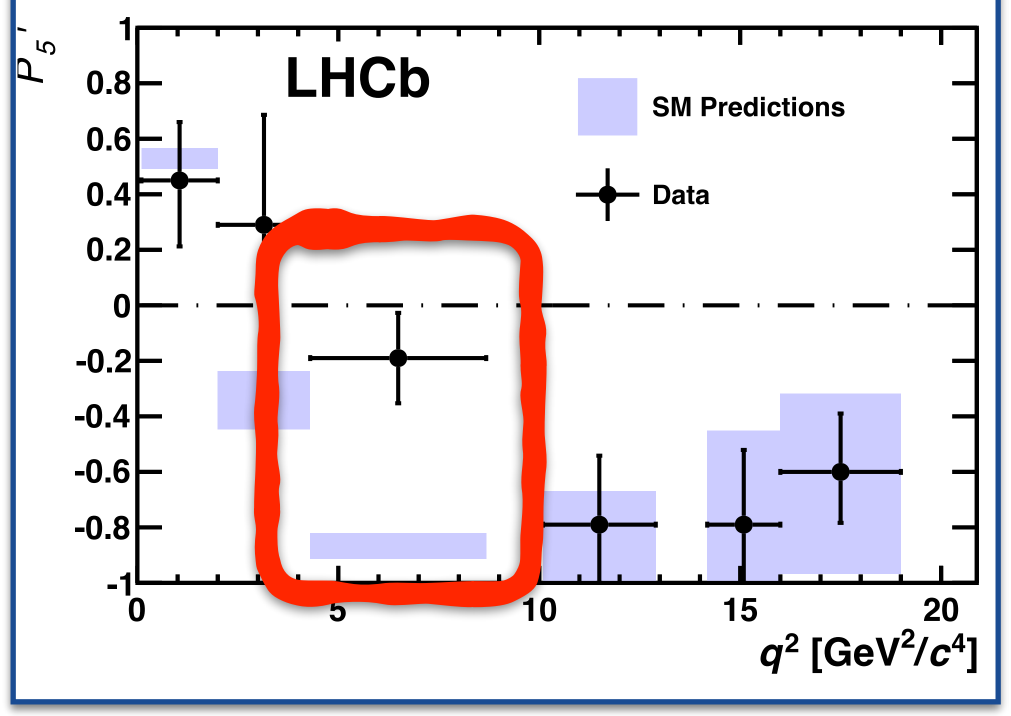
Electromagnetic $C_7^{(\prime)}$

Vector $C_9^{(\prime)}$

Axial vector $C_{10}^{(\prime)}$

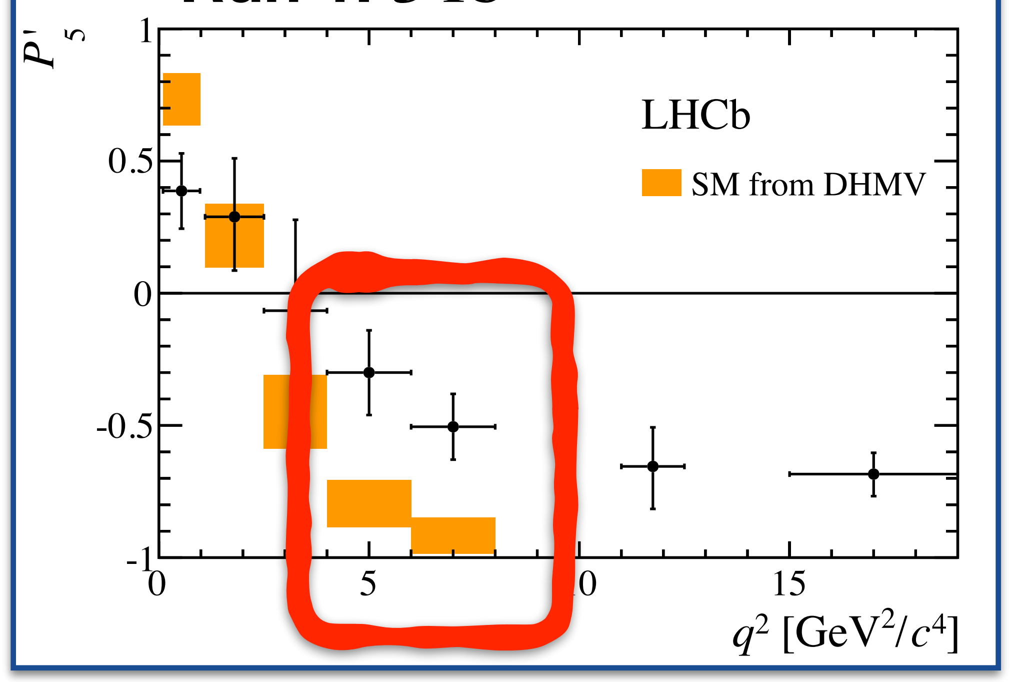
Tensions have remained for ~10 years

2011: $1\ \text{fb}^{-1}$



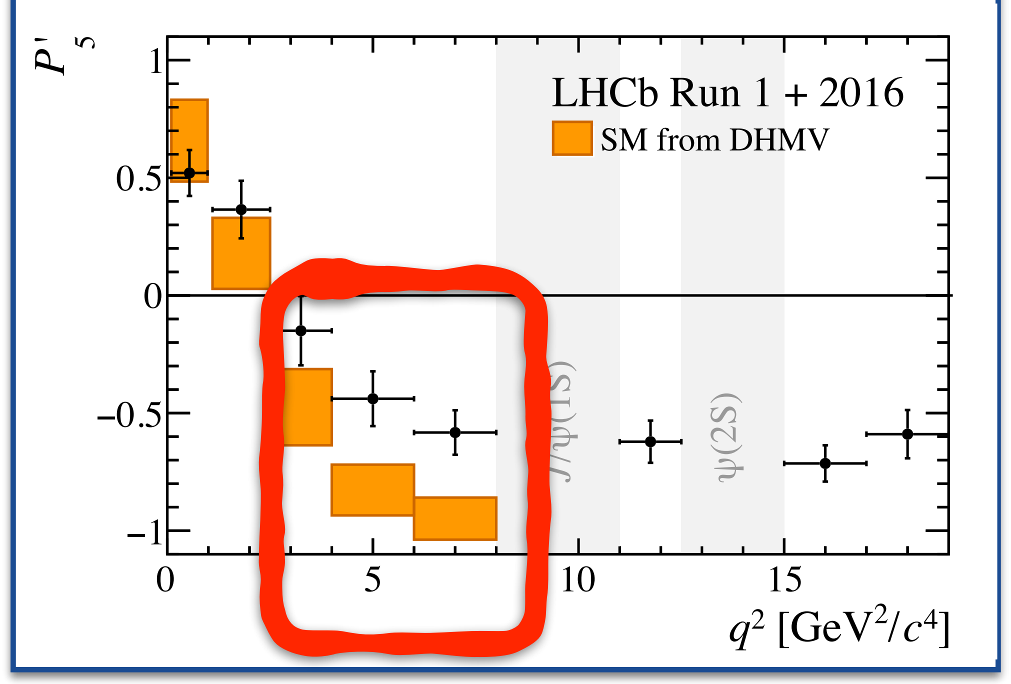
[LHCb-PAPER-2013-037]

Run 1: $3\ \text{fb}^{-1}$



[LHCb-PAPER-2015-051]

Run 1 + 2016: $4.7\ \text{fb}^{-1}$



[LHCb-PAPER-2020-002]

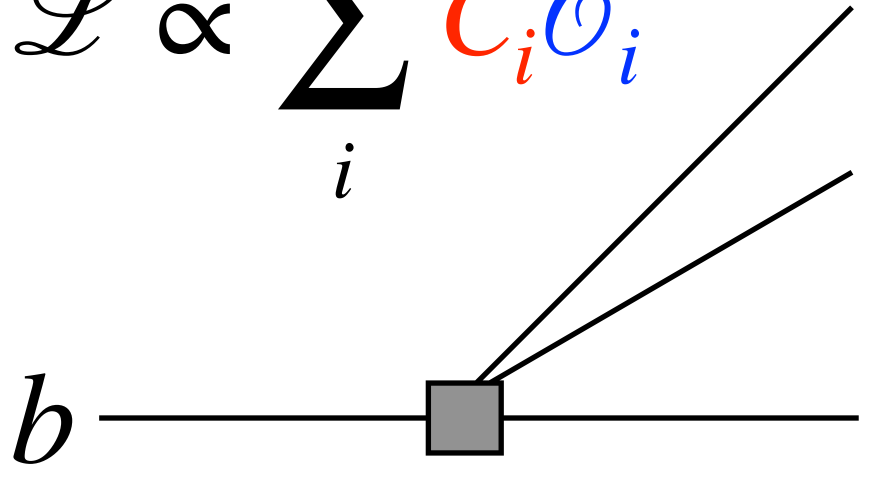
Discrepancies are present in multiple observables and the differential decay rate

$B^0 \to K^{*0}\mu^+\mu^-$: A very brief history

$B^0 \to K$

$b \to s\mu^+\mu^-$ **Weak Effective T**

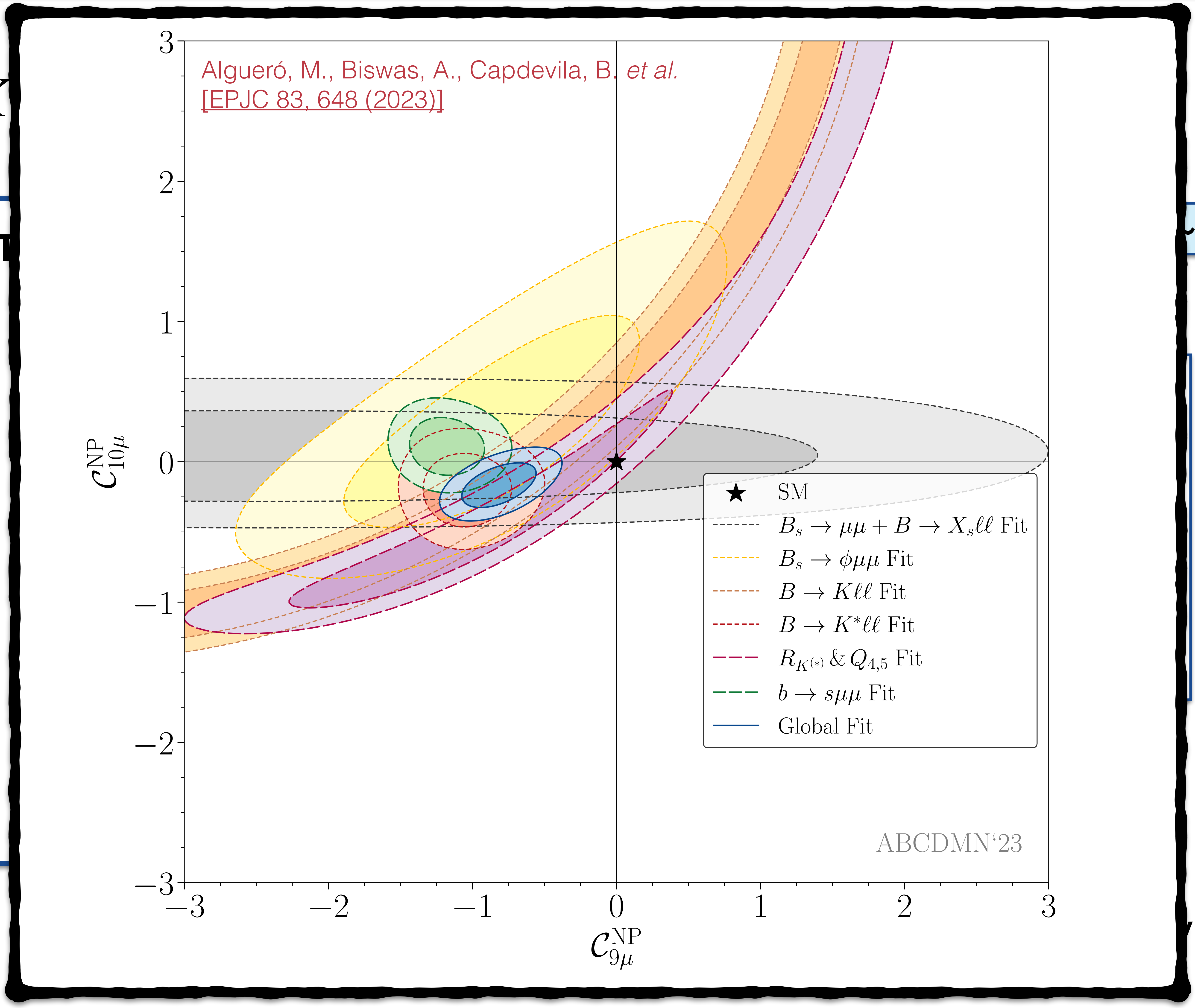
$$\mathscr{L} \propto \sum_i C_i \mathcal{O}_i$$



Electromagnetic $C_7^{(\prime)}$

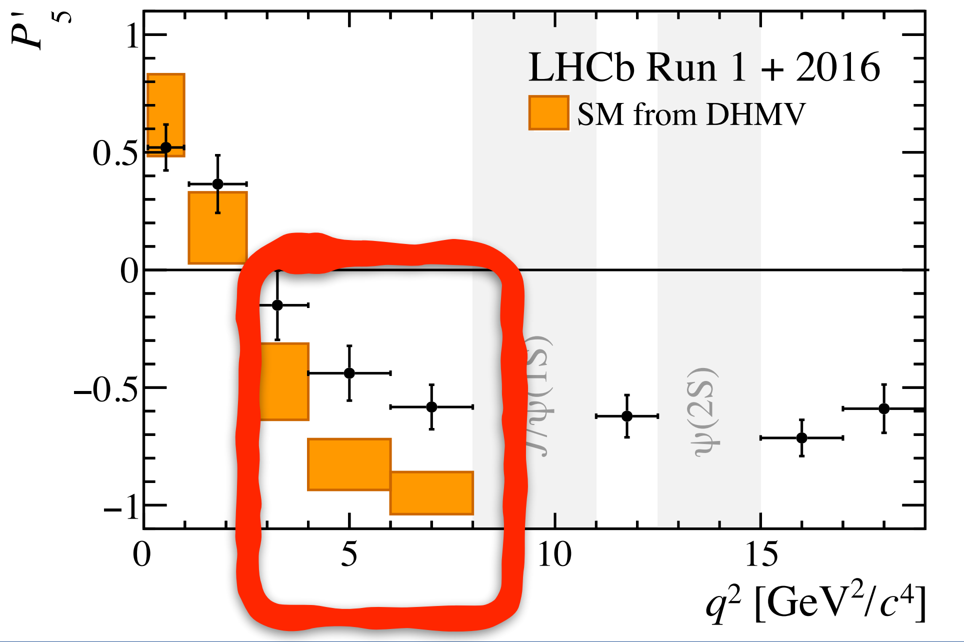
Vector $C_9^{(\prime)}$

Axial vector $C_{10}^{(\prime)}$



~10 years

Run 1 + 2016: 4.7 fb^{-1}



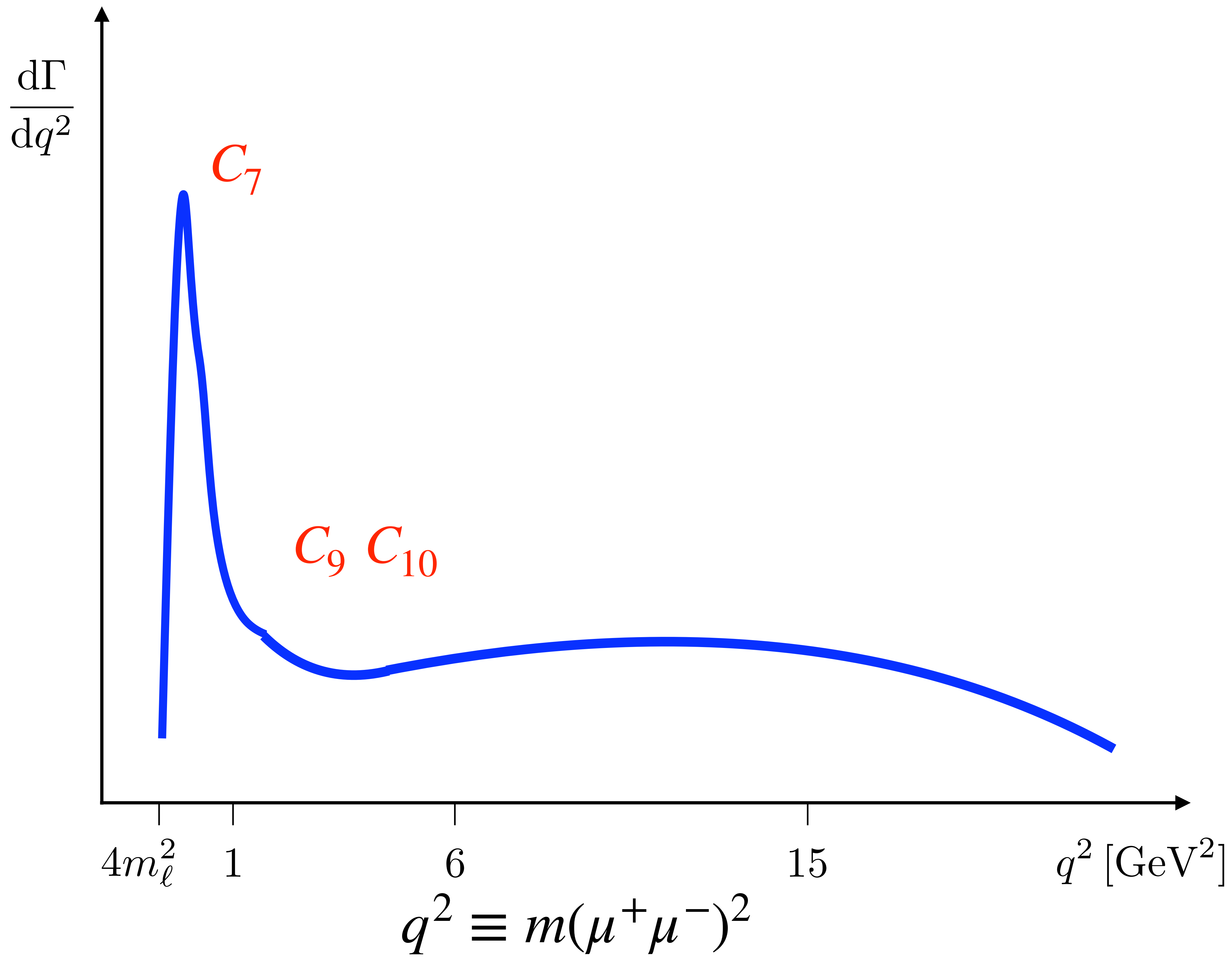
[LHCb-PAPER-2020-002]

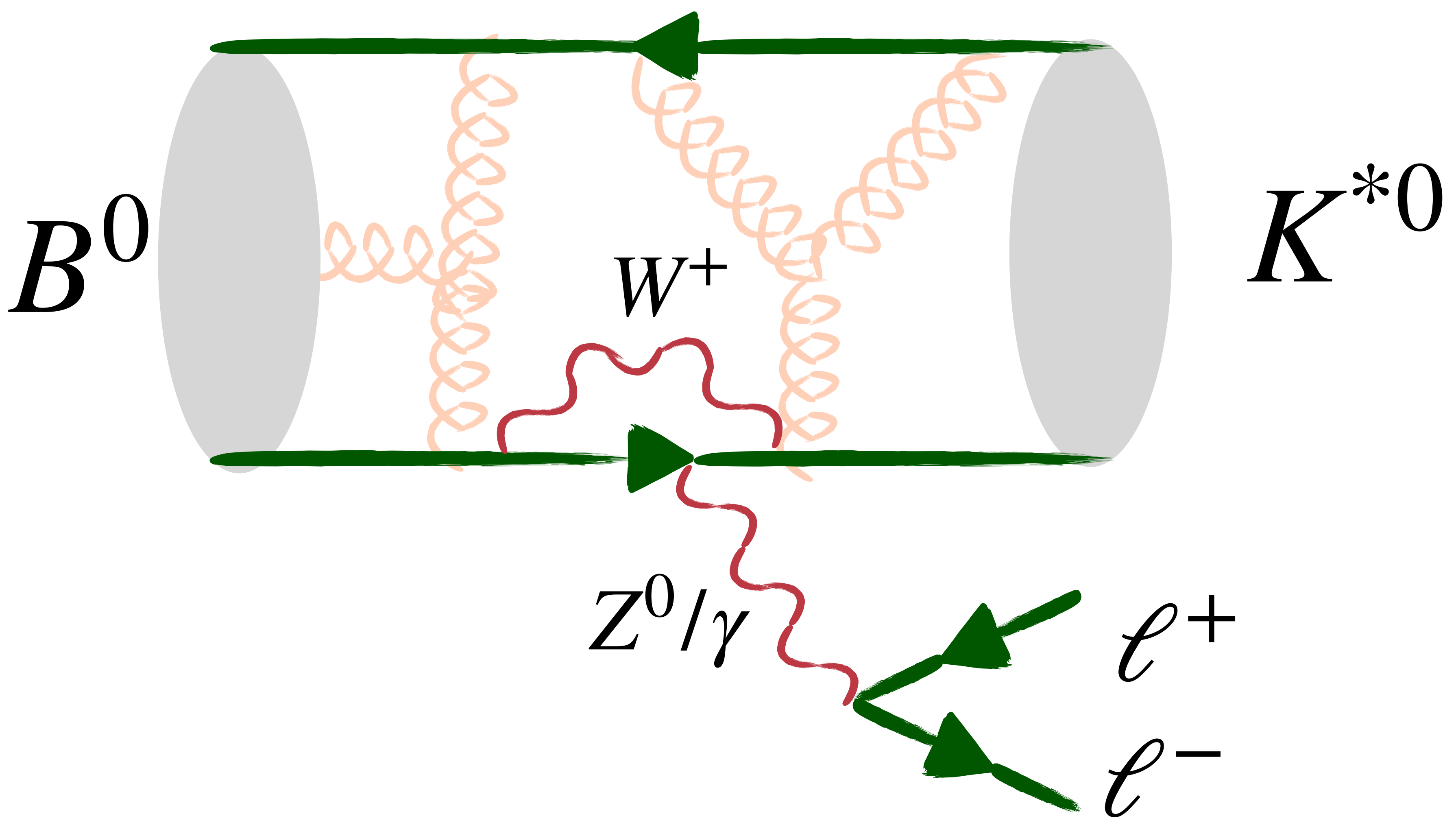
rate

Current measurements point to an anomalous vector contribution

New physics or QCD?

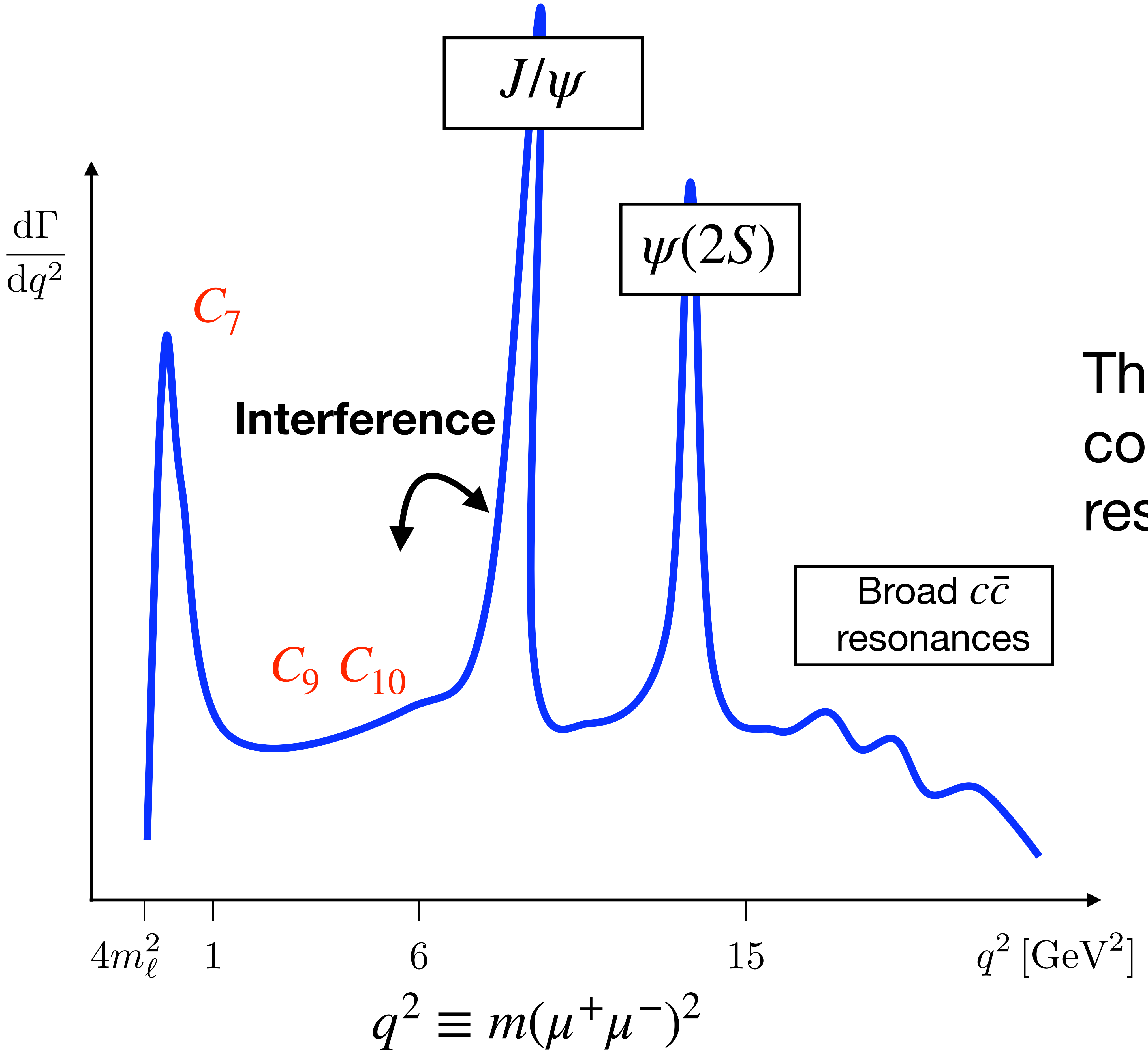
The $B^0 \to K^{*0}\mu^+\mu^-$ decay doesn't live in isolation…

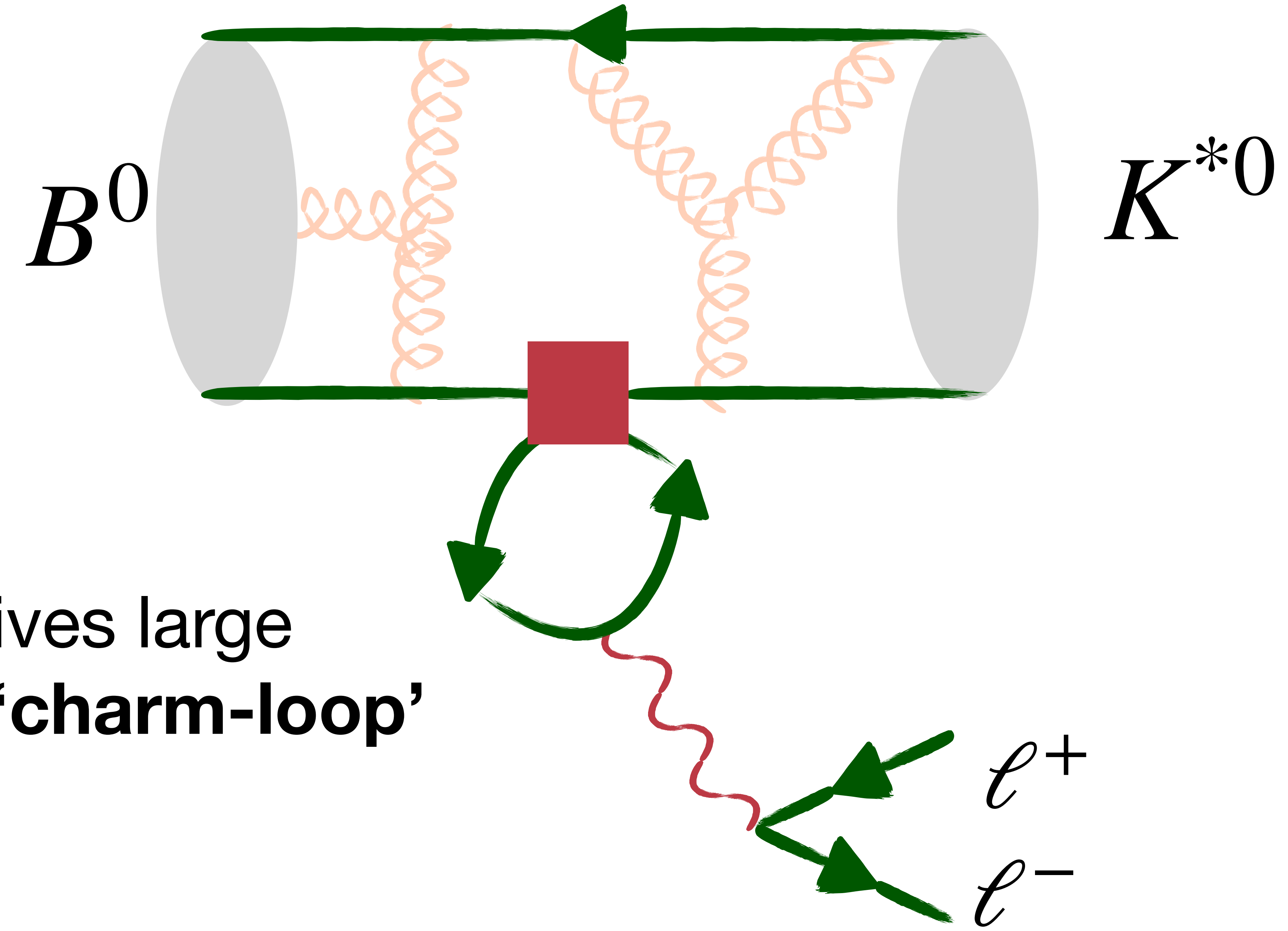




New physics or QCD?

The $B^0 \to K^{*0}\mu^+\mu^-$ decay doesn't live in isolation…

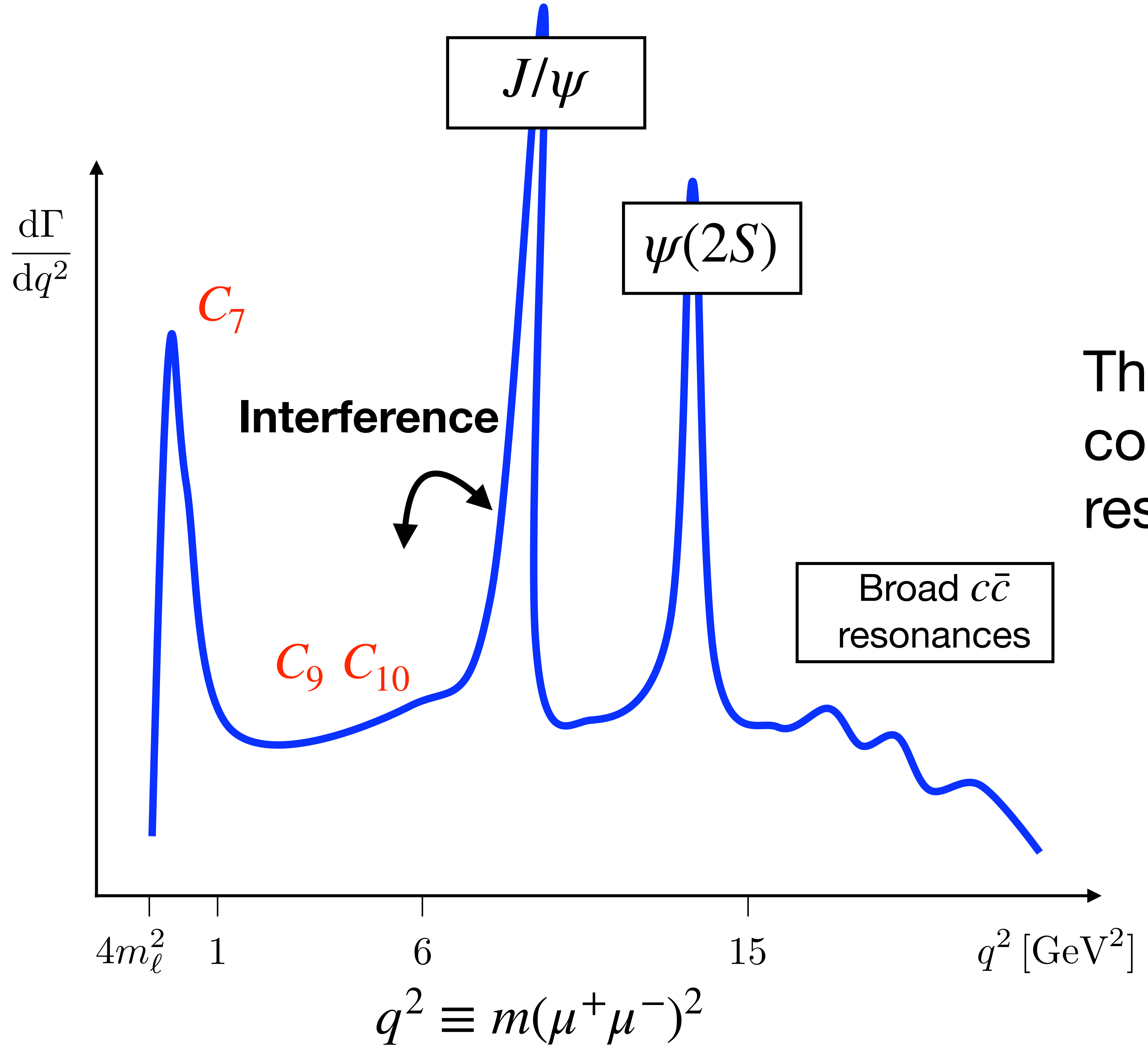


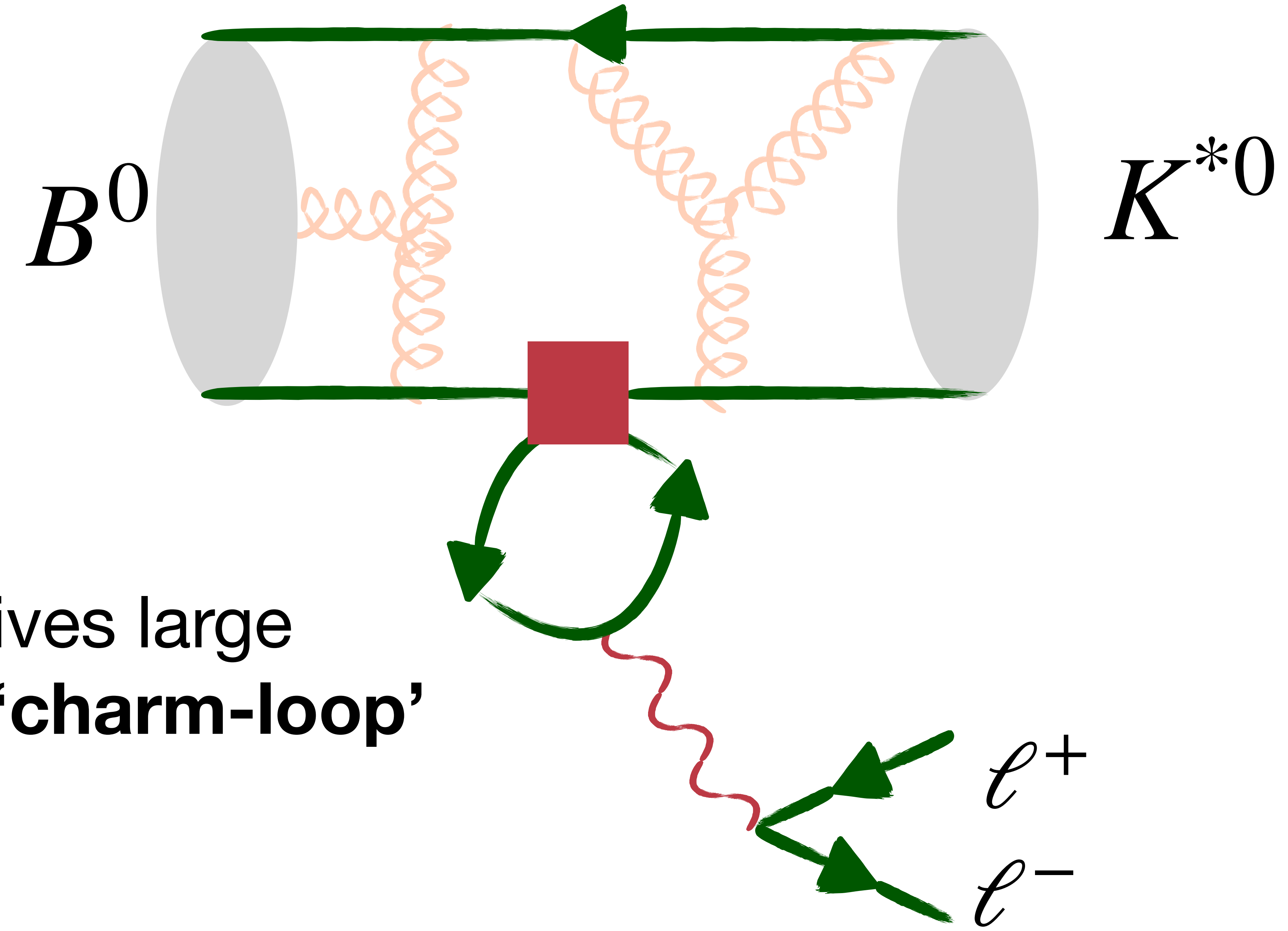


The final state receives large contributions from **'charm-loop'** resonances

New physics or QCD?

The $B^0 \to K^{*0}\mu^+\mu^-$ decay doesn't live in isolation…





The final state receives large contributions from **'charm-loop'** resonances

Many of the contributions are vector-like

→ This mimics the C_9 contribution

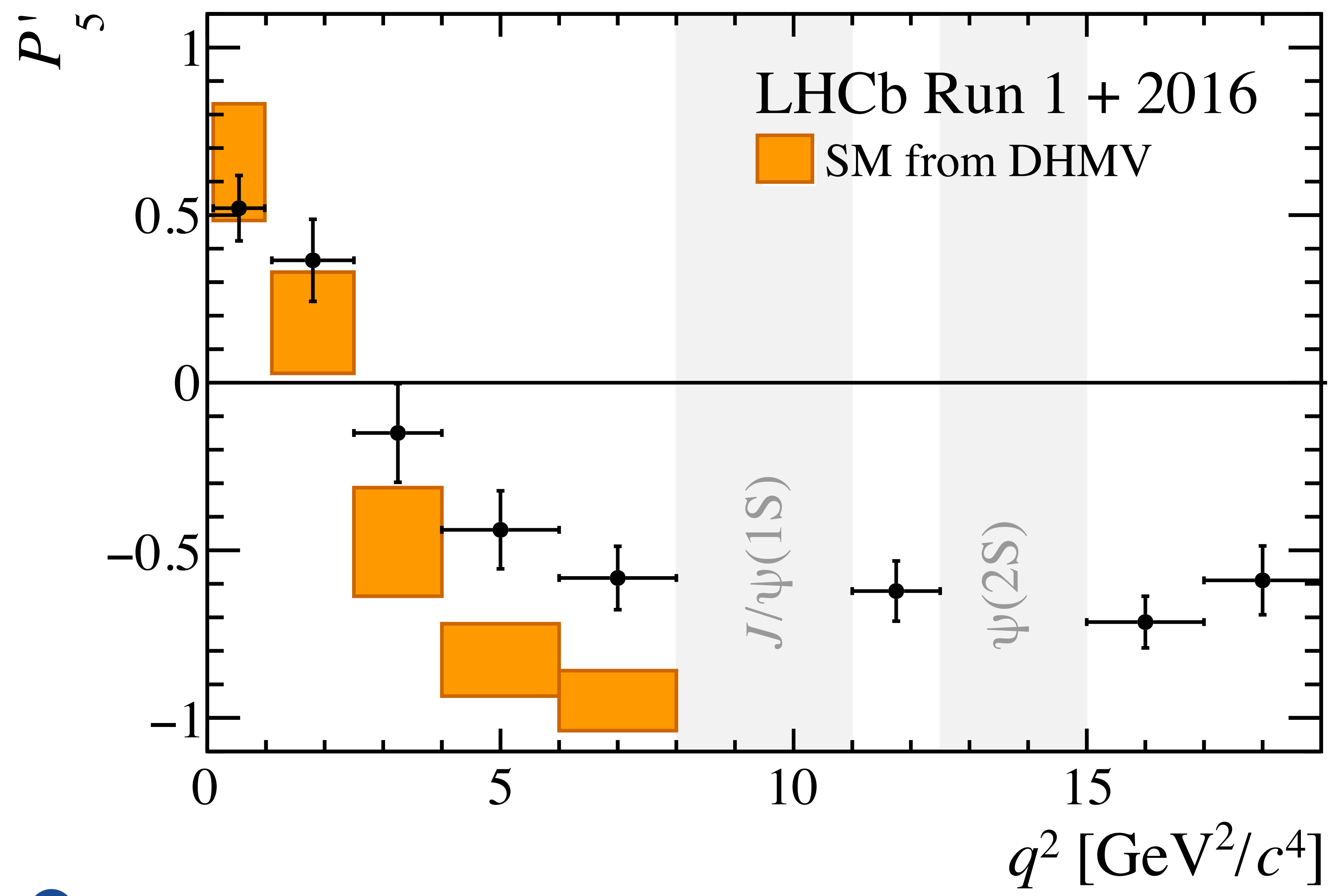
Can we model them?

Current status

Run 1 + 2016: 4.7 fb^{-1}

Binned measurements

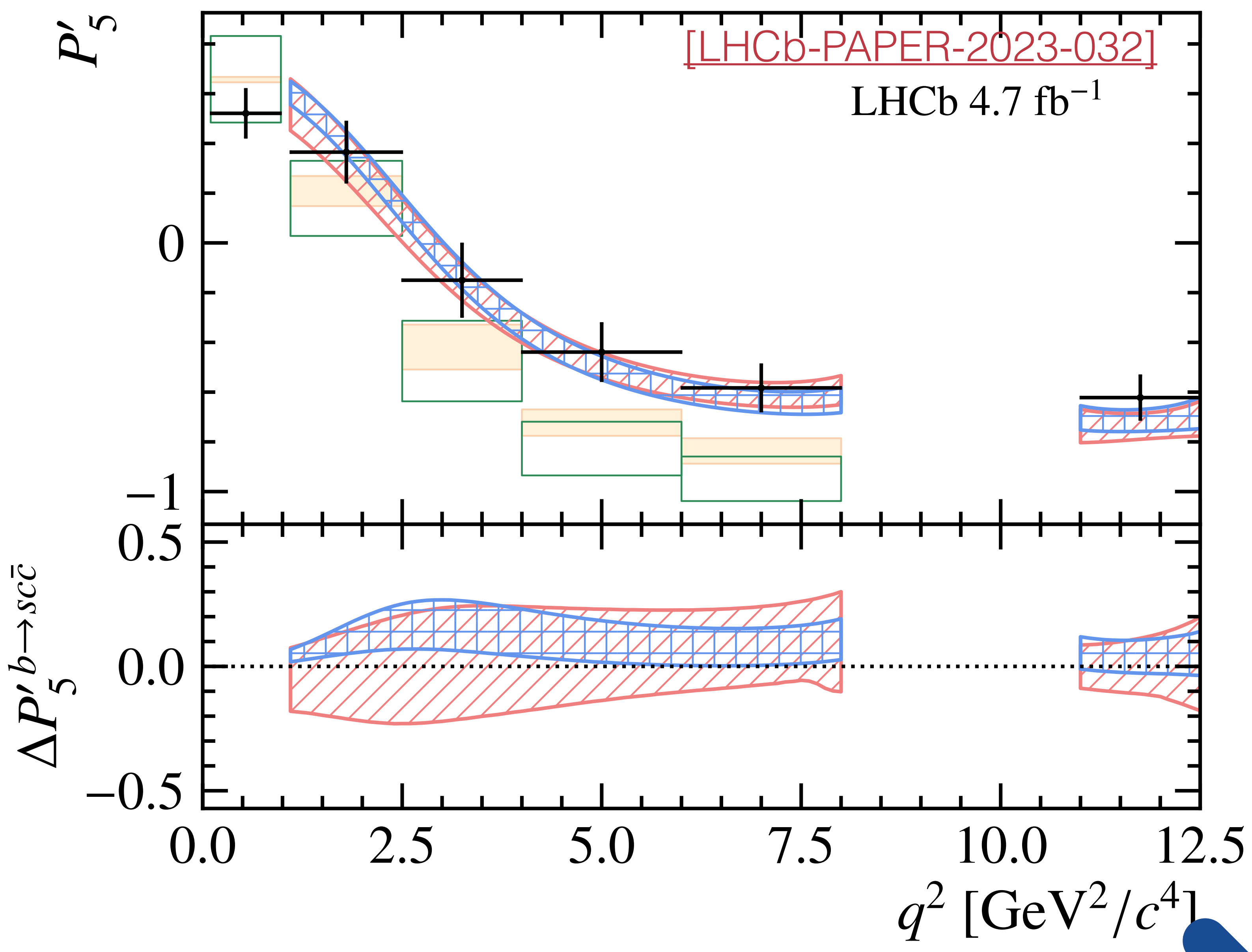
[LHCb-PAPER-2020-002]



Model independent

Measure observables in bins of q^2

Unbinned measurements



Model dependent

Use model of local and nonlocal contributions to extract Wilson coefficients directly

New results

- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local — Non-local contributions

$$C_9^{\mathrm{eff},\lambda}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

New results

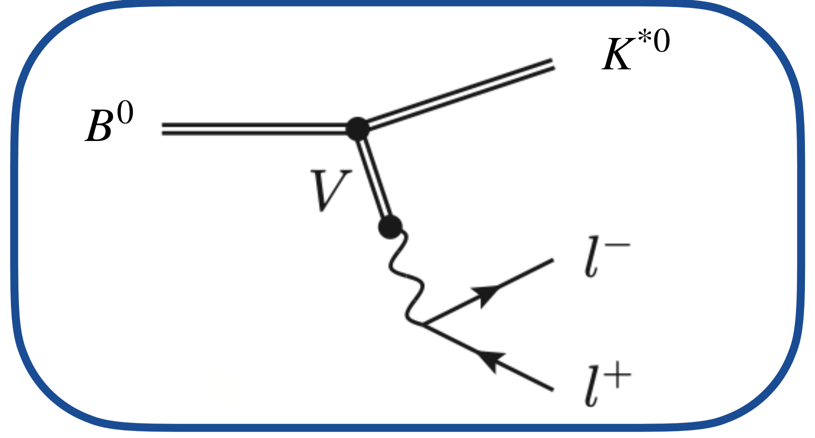
- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local | Non-local contributions

$$C_9^{\mathrm{eff},\lambda}(q^2) = C_9^\mu + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^\mu + \epsilon^\lambda e^{i\omega^0}$$



1-particle contributions

Includes:

$\omega(782)$,	$\psi(2S)$,
$\rho(770)$,	$\psi(3770)$,
$\phi(1020)$,	$\psi(4040)$,
J/ψ,	$\psi(4160)$

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

New results

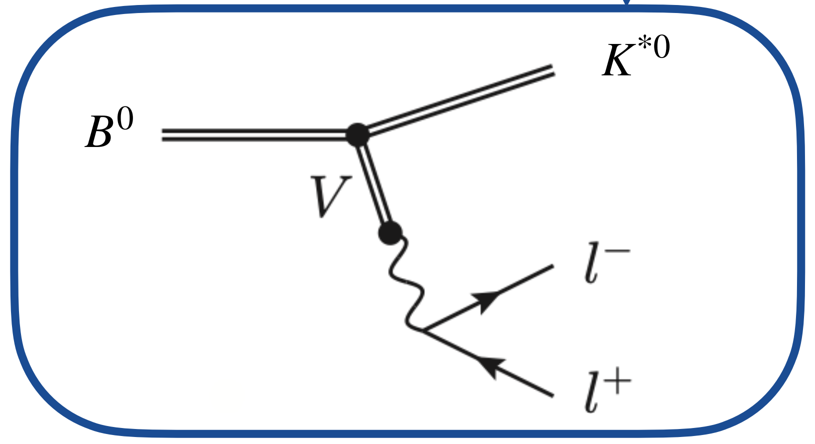
- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local | Non-local contributions

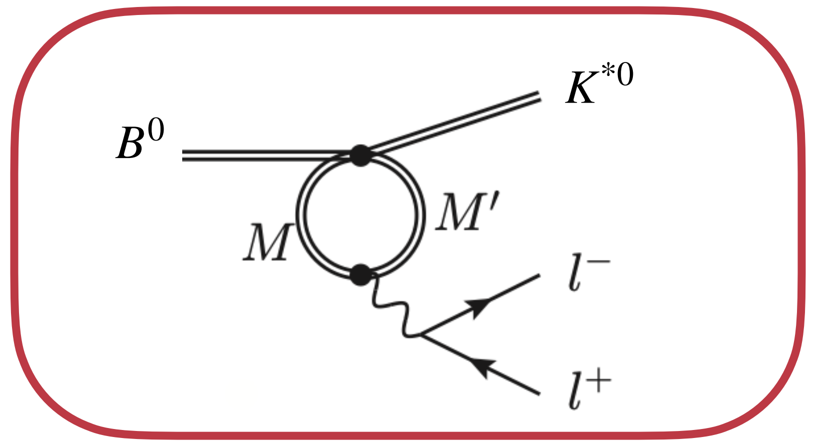
$$C_9^{\mathrm{eff},\lambda}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$



1-particle contributions

Includes:
$\omega(782)$, $\rho(770)$, $\phi(1020)$, J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$



2-particle contributions

Includes:
$D\bar{D}$, $D^*\bar{D}$, $D^*\bar{D}^*$

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

New results

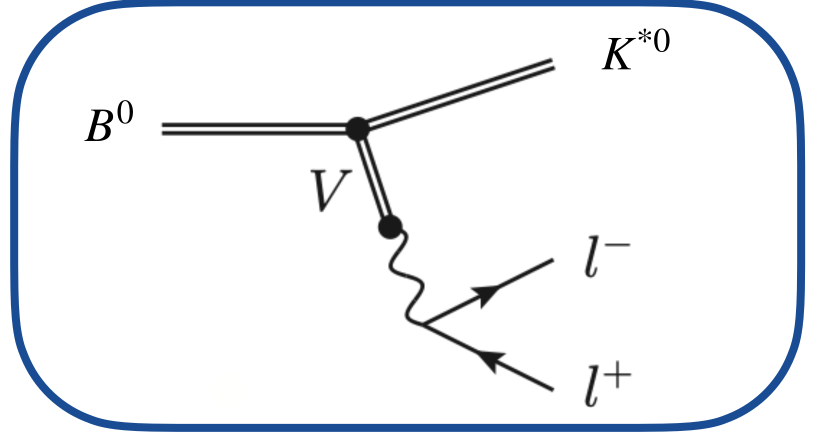
- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local | Non-local contributions

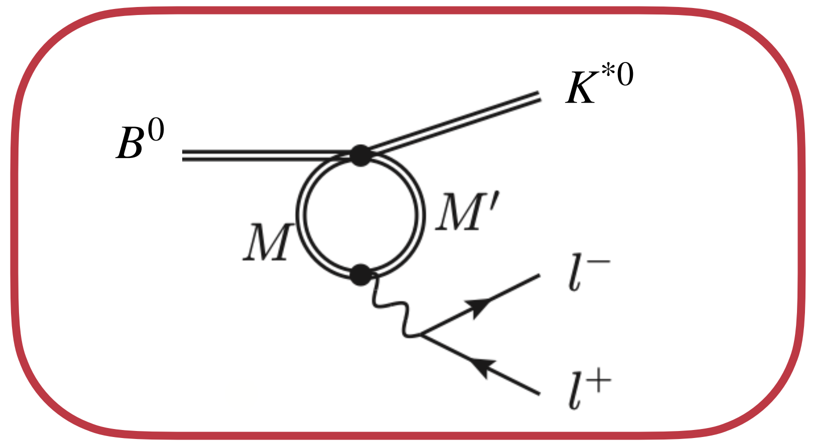
$$C_9^{\text{eff},\lambda}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\text{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\text{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$



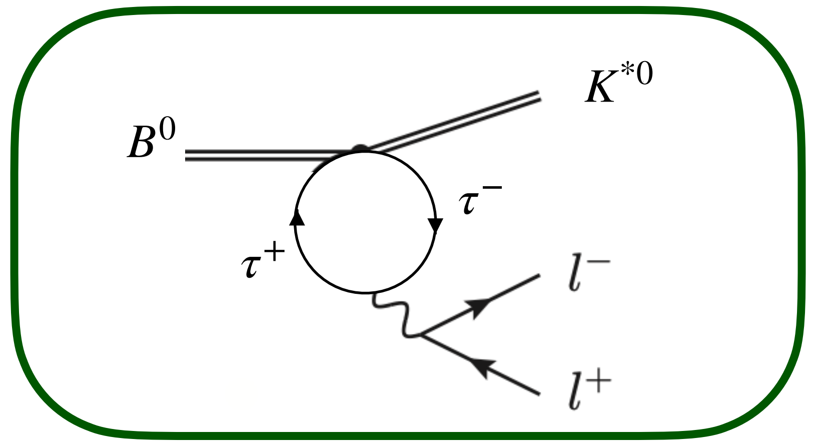
1-particle contributions

Includes:
$\omega(782)$, $\rho(770)$, $\phi(1020)$, J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$



2-particle contributions

Includes:
$D\overline{D}$, $D^*\overline{D}$, $D^*\overline{D}^*$



Tau loop contribution

Sensitive to C_9^{τ}

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

New

New results

- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local | Non-local contributions

$$C_9^{\mathrm{eff},\lambda}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

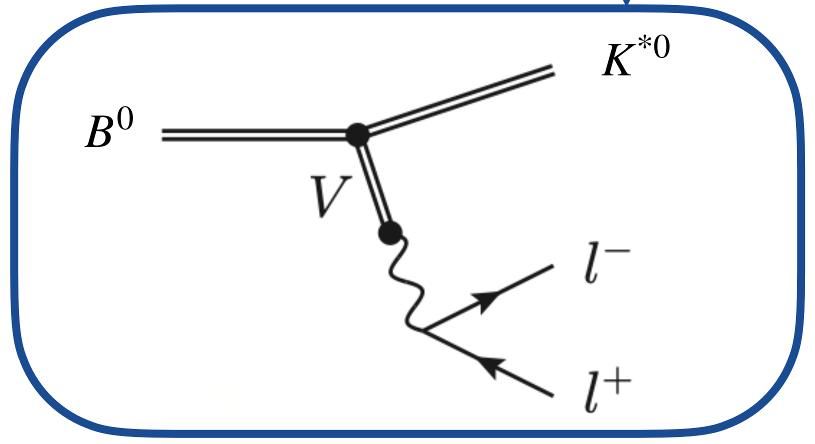
$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

This is determined theoretically at negative q^2 values

Subtraction term

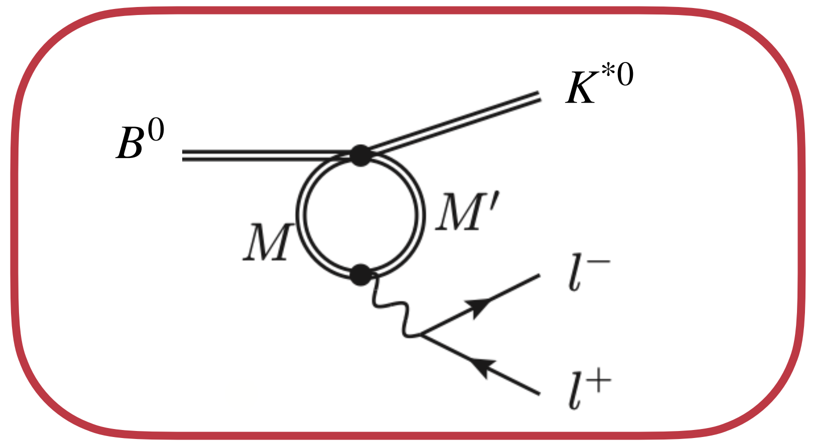
Asatrian, Greub, Virto [JHEP 04 (2020) 012]

Negligible impact from light quarks



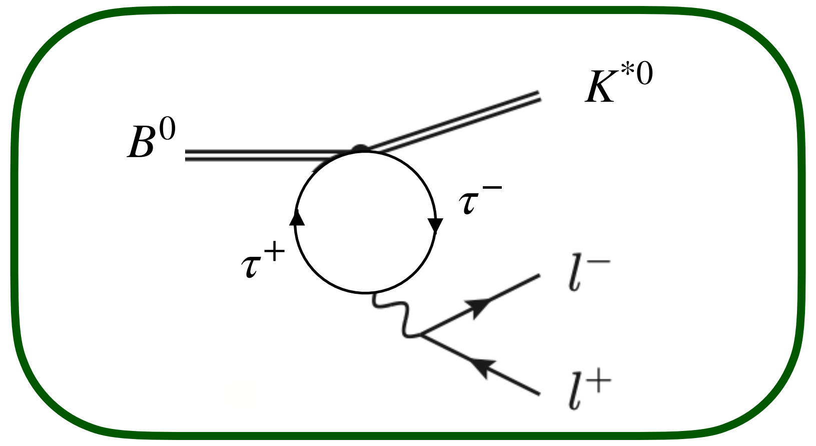
1-particle contributions

Includes:
$\omega(782)$, $\rho(770)$, $\phi(1020)$, J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$



2-particle contributions

Includes:
$D\bar{D}$, $D^*\bar{D}$, $D^*\bar{D}^*$



Tau loop contribution

Sensitive to C_9^{τ}

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

New results

- ✓ **Unbinned** amplitude analysis to the whole $q^2 \equiv m^2(\mu^+\mu^-)$ region
- ✓ **First measurement** using the full Run1 [2011-2012] and Run2 [2016-2018] data

Dispersion Relation

Local | Non-local contributions

$$C_9^{\mathrm{eff},\lambda}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

ΔC_7^{λ}

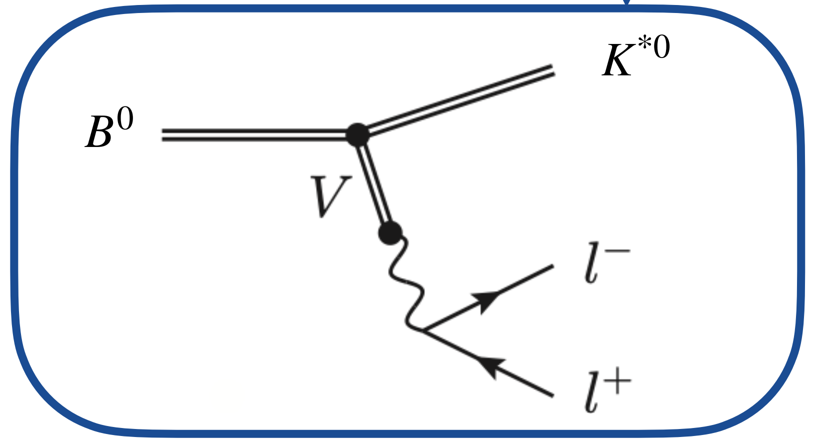
Polarisation dependent shift to C_7

This is determined theoretically at negative q^2 values

Subtraction term

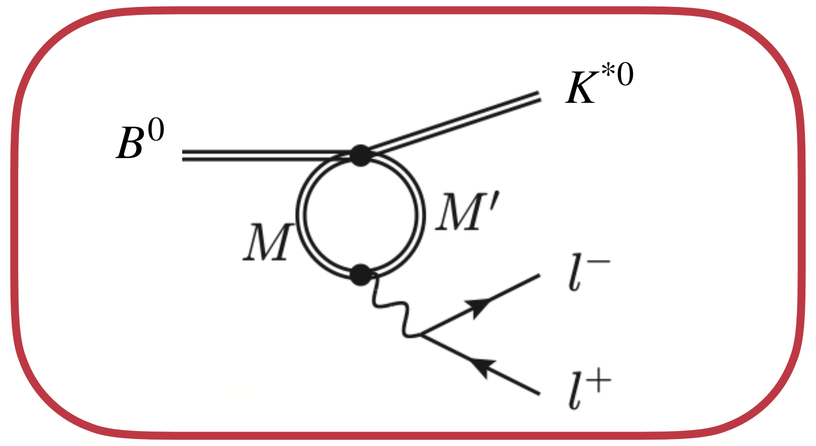
Asatrian, Greub, Virto [JHEP 04 (2020) 012]

Negligible impact from light quarks



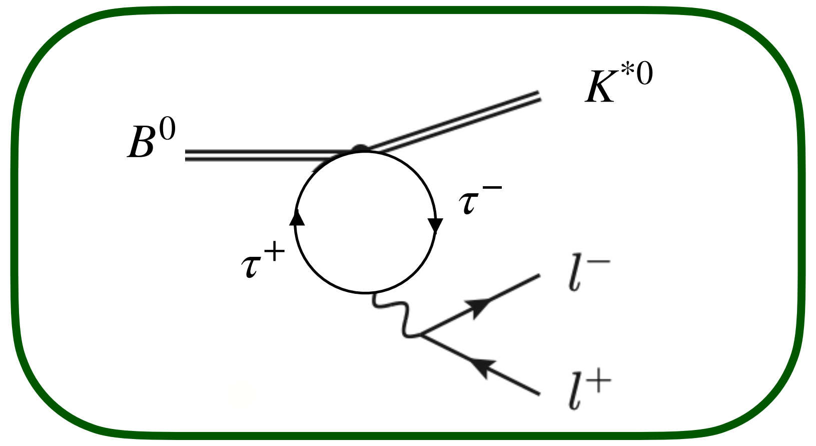
1-particle contributions

Includes:
$\omega(782)$, $\rho(770)$, $\phi(1020)$, J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$



2-particle contributions

Includes:
$D\bar{D}$,
$D^*\bar{D}$,
$D^*\bar{D}^*$



Tau loop contribution

Sensitive to C_9^{τ}

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

Analysis strategy

Angular analysis preformed in the three decay angles and q^2

From Simulation

- Acceptance model

From Data

- Resolution
- S-wave parameters
- Background model

From Theory

- Local $B \to K^*$ Form factors

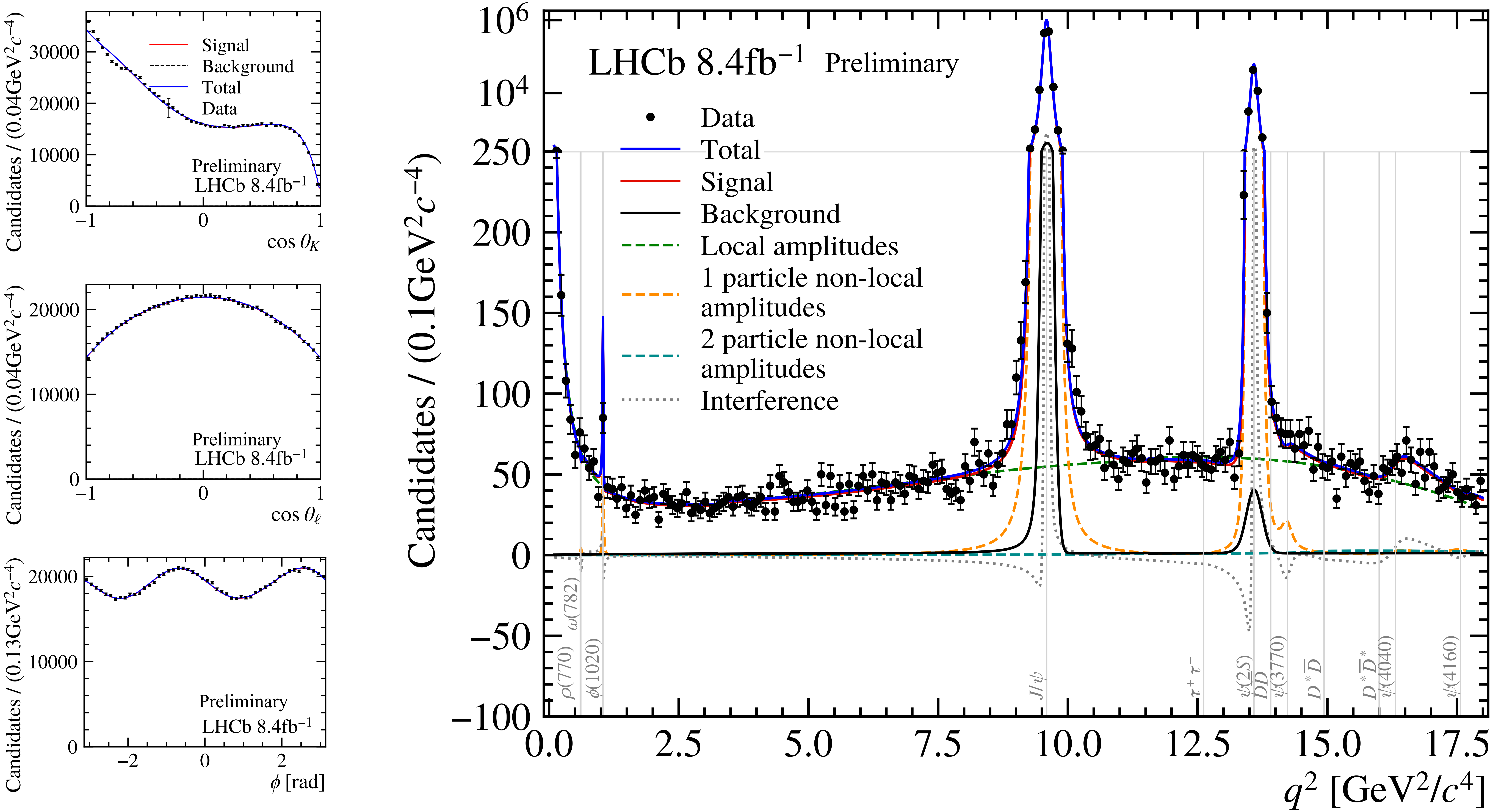
Gaussian constrained GRvDV [JHEP 09, 133 (2022)]

Fit determines 150 parameters:

- $\Re(C_9)$, $\Re(C_{10})$. $\Re(C_9')$, $\Re(C_{10}')$, $\Re(C_9^\tau)$
- Mag. and Phase of 1-particle resonances
- Real+Imag $D^{(*)}\overline{D}^{(*)}$ per helicity
- ΔC_7 per helicity
- Form factors

New

Results


Signal
Background
Total
Data
Preliminary
LHCb 8.4fb^{-1}
Candidates / (0.04GeV$^2c^{-4}$)
$\cos\theta_K$
$\cos\theta_\ell$
Candidates / (0.13GeV$^2c^{-4}$)
ϕ [rad]
LHCb 8.4fb^{-1} Preliminary
Data
Total
Signal
Background
Local amplitudes
1 particle non-local amplitudes
2 particle non-local amplitudes
Interference
Candidates / (0.1GeV$^2c^{-4}$)
q^2 [GeV$^2/c^4$]
$\rho(770)$
$\omega(782)$
$\phi(1020)$
J/ψ
$\tau^+\tau^-$
$\psi(2S)$
$D\bar{D}$
$\psi(3770)$
$D^*\bar{D}$
$D^*\bar{D}^*$
$\psi(4040)$
$\psi(4160)$

Wilson Coefficients

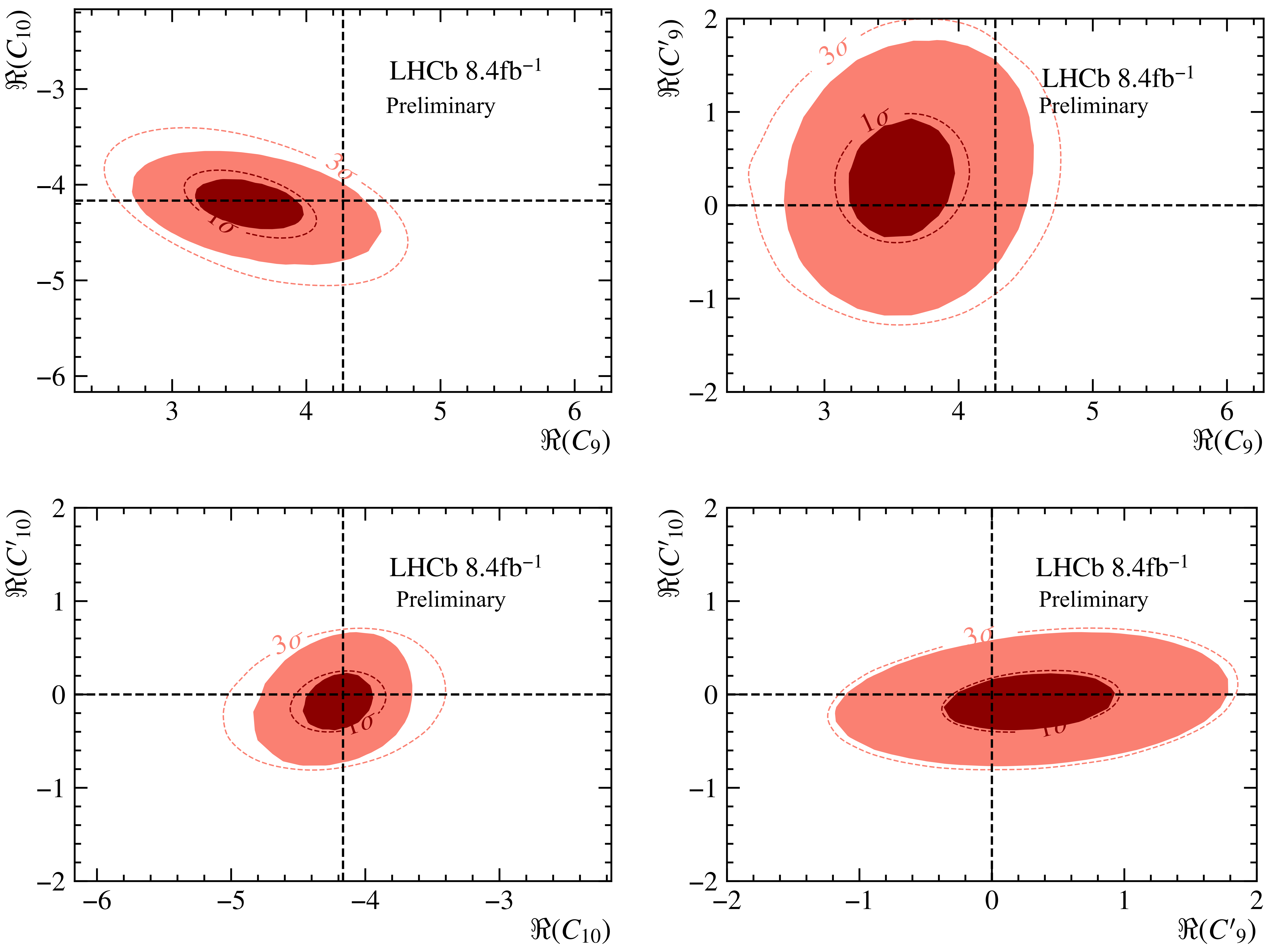
Biggest deviation is C_9 with $\Delta C_9^{NP} = -0.71$ at 2.1σ from SM

$\mathcal{C}_9$	$3.56 \pm 0.28 \pm 0.18$	2.1σ
$\mathcal{C}_{10}$	$-4.02 \pm 0.18 \pm 0.16$	0.6σ
$\mathcal{C}'_9$	$0.28 \pm 0.41 \pm 0.12$	0.7σ
$\mathcal{C}'_{10}$	$-0.09 \pm 0.21 \pm 0.06$	0.4σ
$\mathcal{C}_9^{\tau}$	$-116 \pm 264 \pm 98$	0.4σ

Global significance $\sim 1.5\sigma$ from SM

In agreement with previous unbinned analysis

$\mathscr{B}(B^0 \to J/\psi K^{*0})$ **dominates systematic uncertainty**

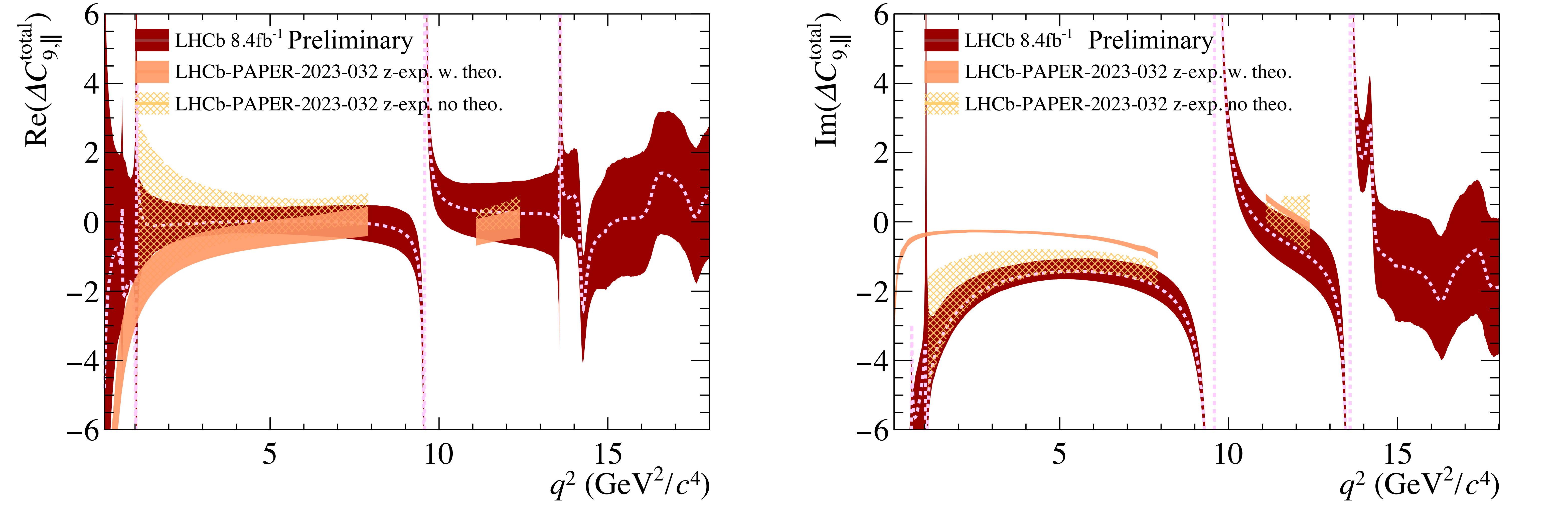


New

Nonlocal amplitudes

Impact of the nonlocal amplitudes on the Wilson coefficients shown per helicity e.g. ||

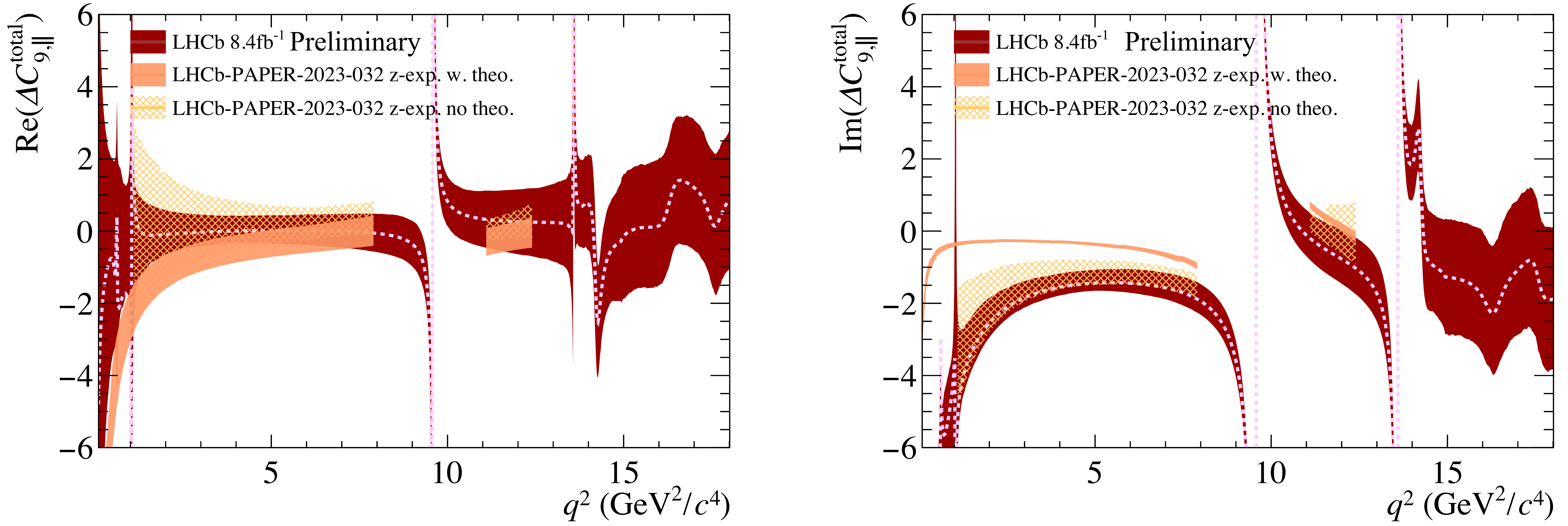
Good agreement with previous analysis



New

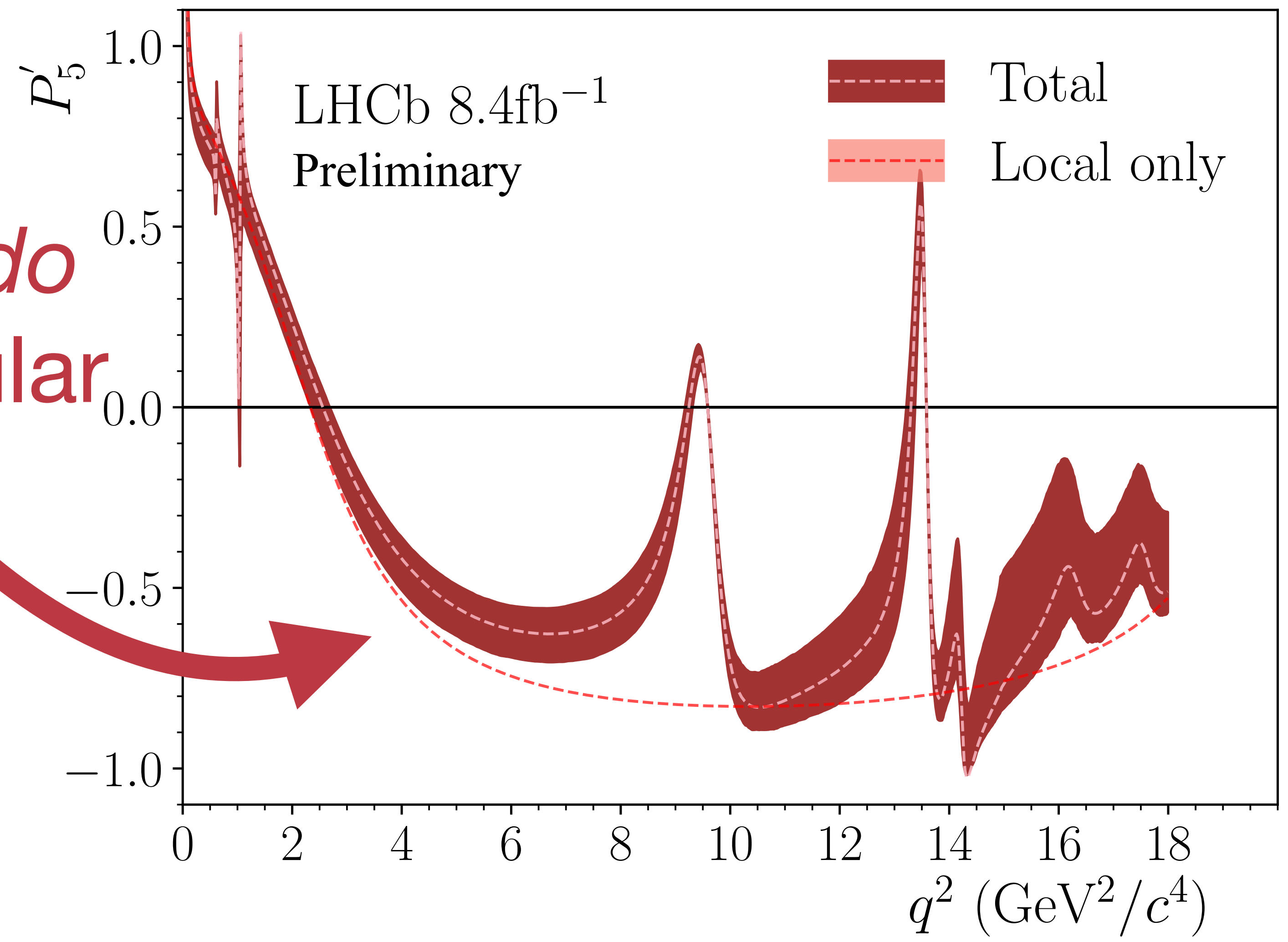
Nonlocal amplitudes

Impact of the nonlocal amplitudes on the Wilson coefficients shown per helicity e.g. ||



Good agreement with previous analysis

Nonlocal contributions *do* influence angular observables

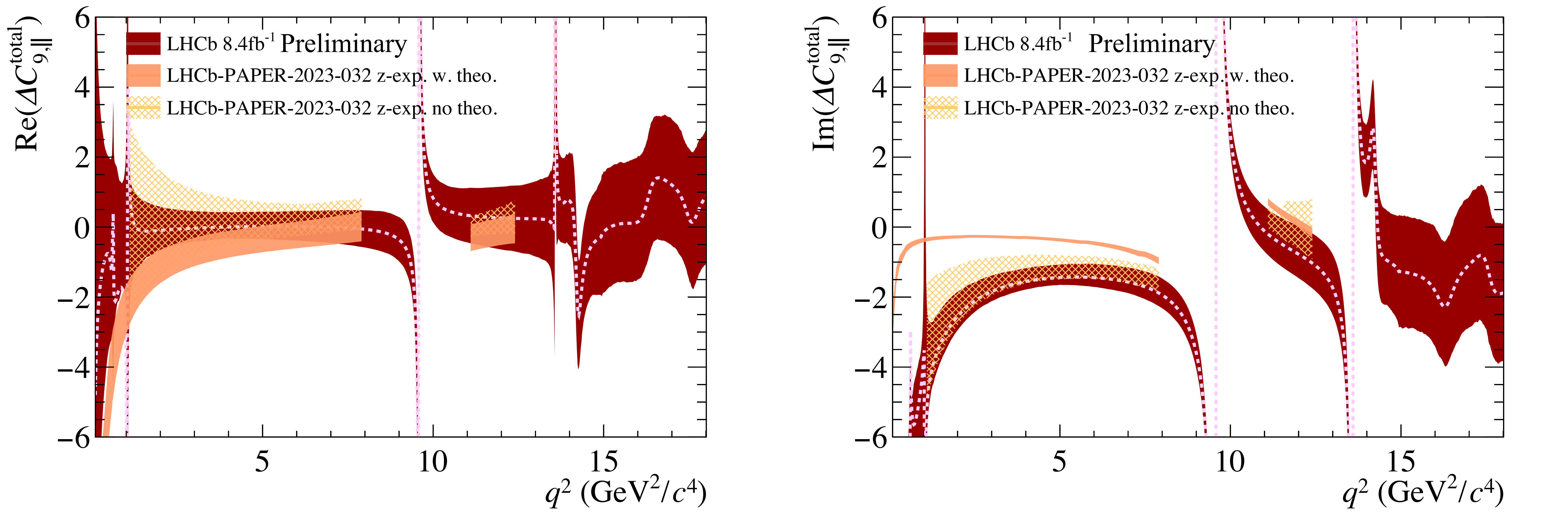


New

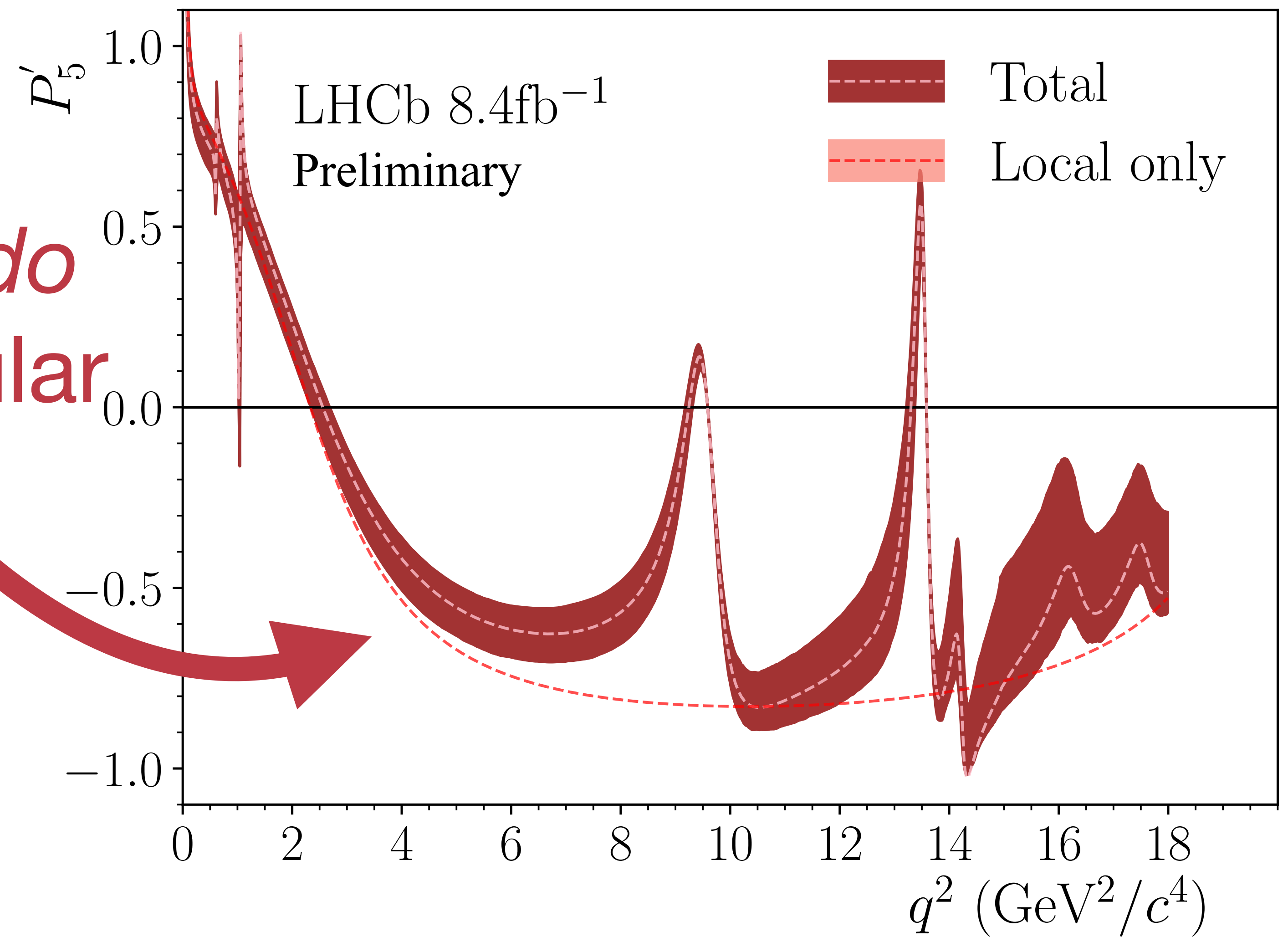
Nonlocal amplitudes

Impact of the nonlocal amplitudes on the Wilson coefficients shown per helicity e.g. ||

Good agreement with previous analysis



Nonlocal contributions *do* influence angular observables



Integrate in bins

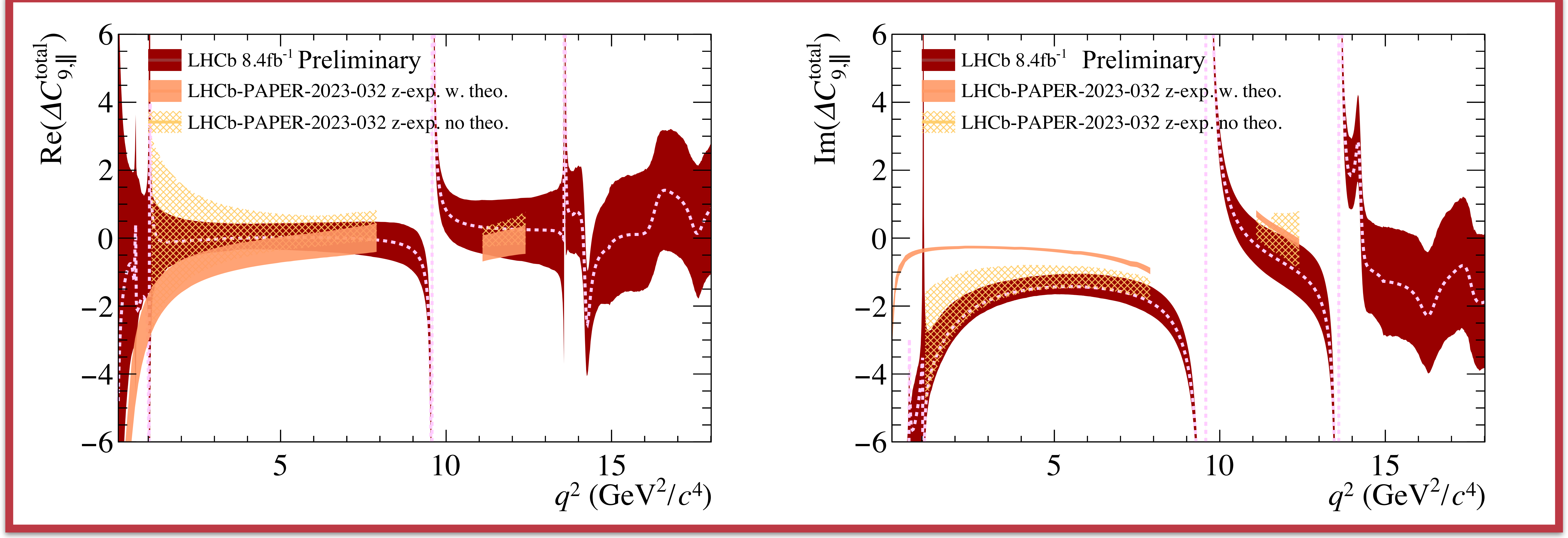
Nonlocal amplitudes

New

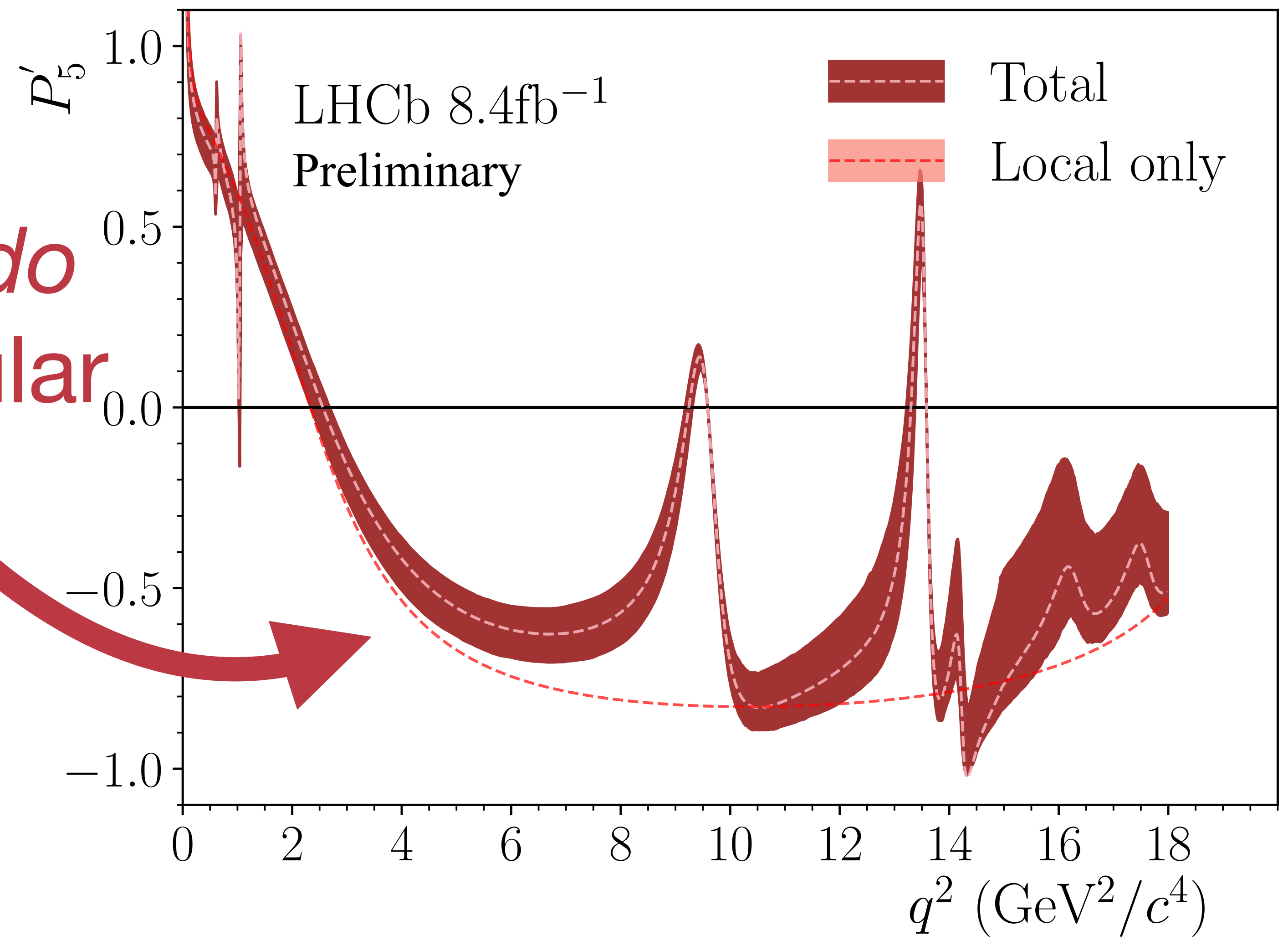
LHCb-PAPER-2024-011,
in preparation

Impact of the nonlocal amplitudes on the Wilson coefficients shown per helicity e.g. ||

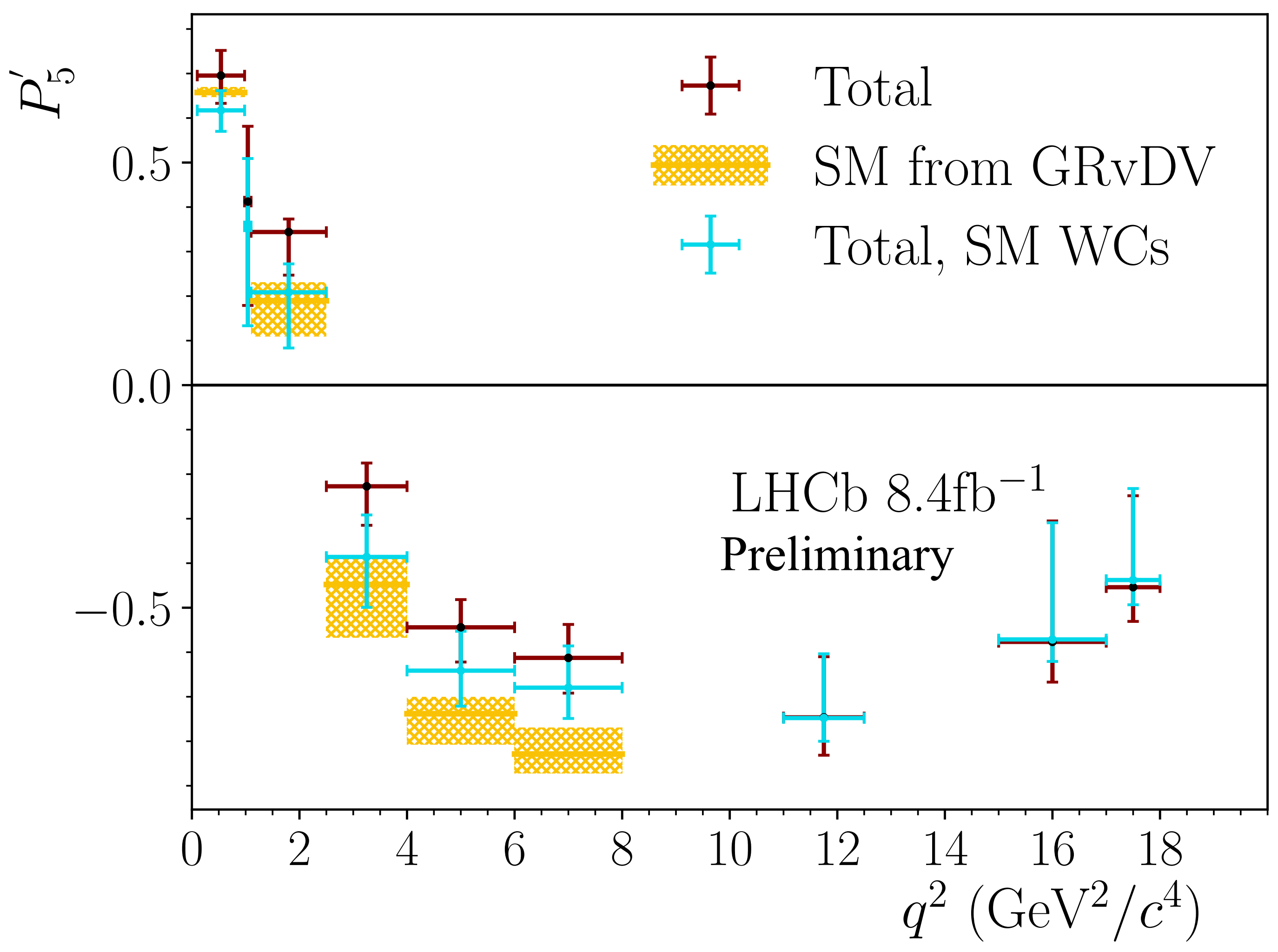
Good agreement with previous analysis



Nonlocal contributions *do* influence angular observables



Integrate in bins



Red vs. Cyan
Impact of allowing NP

Cyan vs. Yellow
Impact of nonlocal modelling

Note: bins are correlated

Conclusions

Observation of $J/\psi \to \mu^+\mu^-\mu^+\mu^-$ decays

World's best

$$\mathcal{B}(J/\psi \to \mu^+\mu^-\mu^+\mu^-) = (1.13 \pm 0.10 \pm 0.05 \pm 0.01) \times 10^{-6}$$

Measurement of local and nonlocal amplitudes in $B^0 \to K^{*0}\mu^+\mu^-$ decays

First LHCb $B^0 \to K^{*0}\mu^+\mu^-$ angular analysis with Run 1 + Run 2 data set

Key takeaway: Nonlocal contributions found to only mildly impact the results

$\mathcal{C}_9$	$3.56 \pm 0.28 \pm 0.18$	2.1σ
$\mathcal{C}_{10}$	$-4.02 \pm 0.18 \pm 0.16$	0.6σ
$\mathcal{C}'_9$	$0.28 \pm 0.41 \pm 0.12$	0.7σ
$\mathcal{C}'_{10}$	$-0.09 \pm 0.21 \pm 0.06$	0.4σ

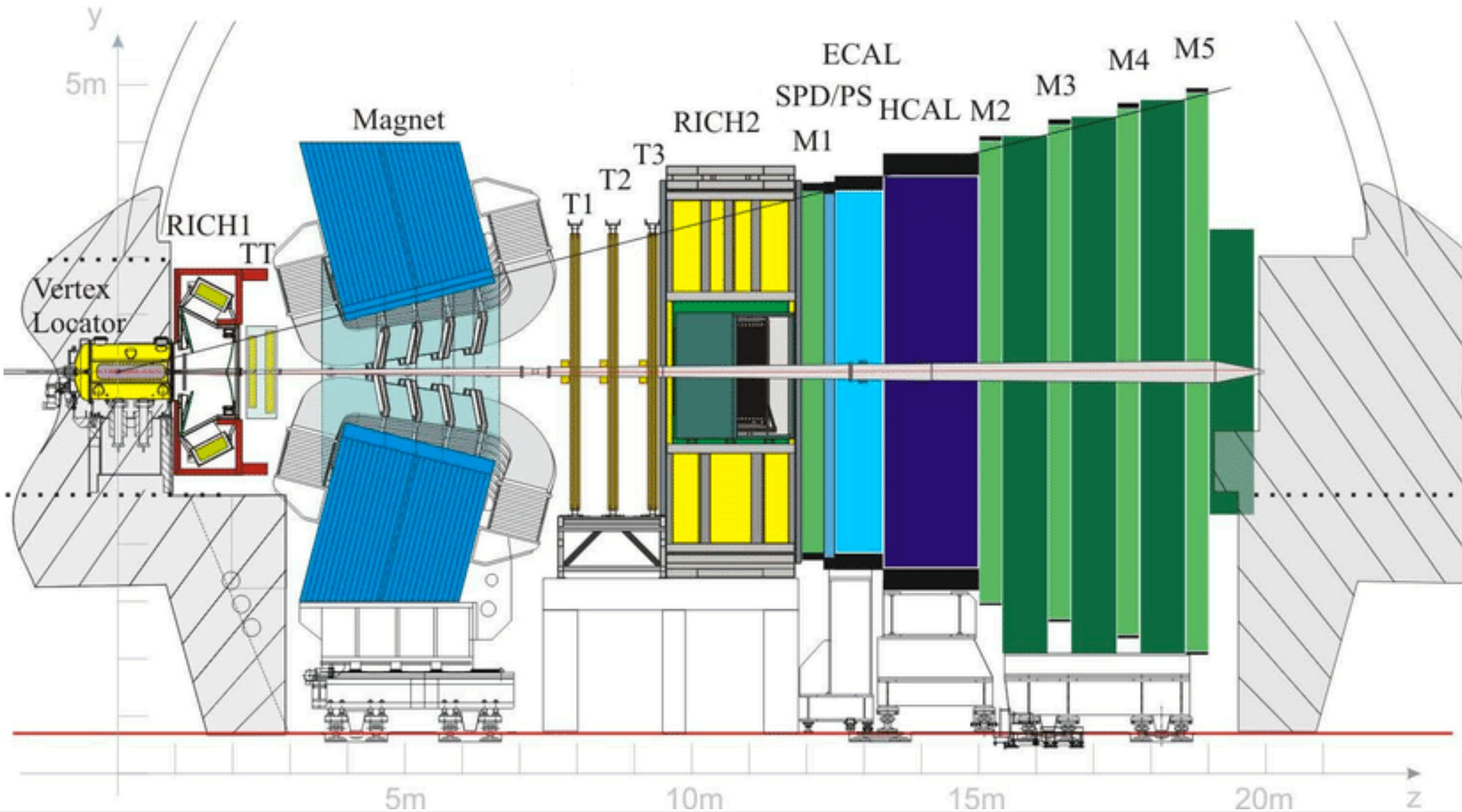
World's first

$\mathcal{C}_9^\tau$	$-116 \pm 264 \pm 98$	0.4σ

First direct measurement of C_9^τ

Back up

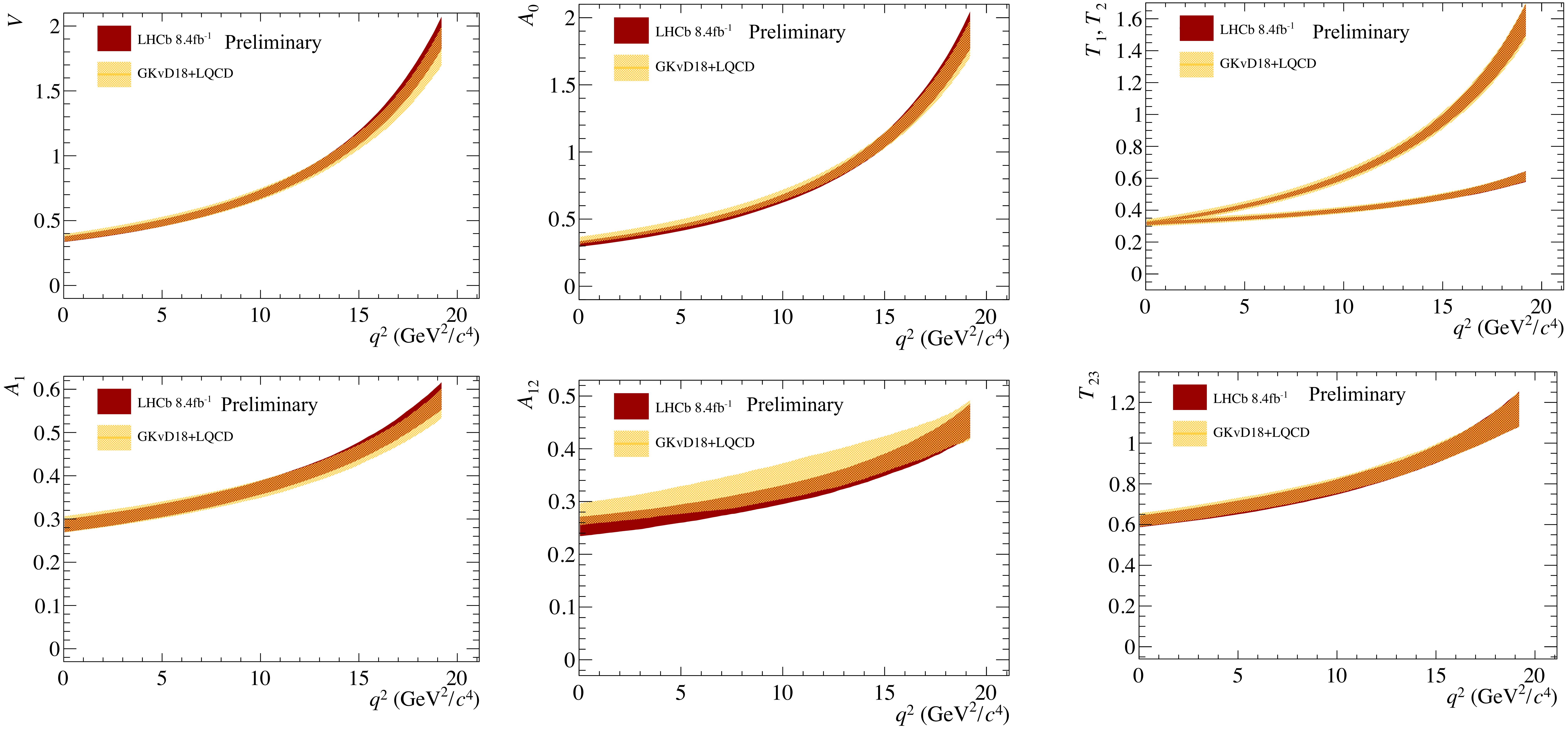
LHCb


y
5m
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
SPD/PS
M1
ECAL
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z

Form factor agreement

LHCb-PAPER-2024-011,
in preparation

Form factor priors are compared to posteriors



Cross checks

LHCb-PAPER-2024-011,
in preparation

q^2 dependence

Fit performed with linearly varying C_9 and C_{10}:

$$C_9^{q^2} = C_9 + \alpha(q^2 - 8.95)$$
$$C_{10}^{q^2} = C_{10} + \beta(q^2 - 8.95)$$

$$\alpha = 0.029 \pm 0.082$$
$$\beta = -0.058 \pm 0.026$$

2.2σ deviation from zero for C_{10} is observed

Form factor dependence

Use alternative local $B \to K^*$ form factors - different LCSR inputs

Bharucha, Straub, & Zwicky [JHEP 08 (2016) 098]

C_9 changes by 35% σ_{stat}

C_{10} changes by 90% σ_{stat}

Subtraction point

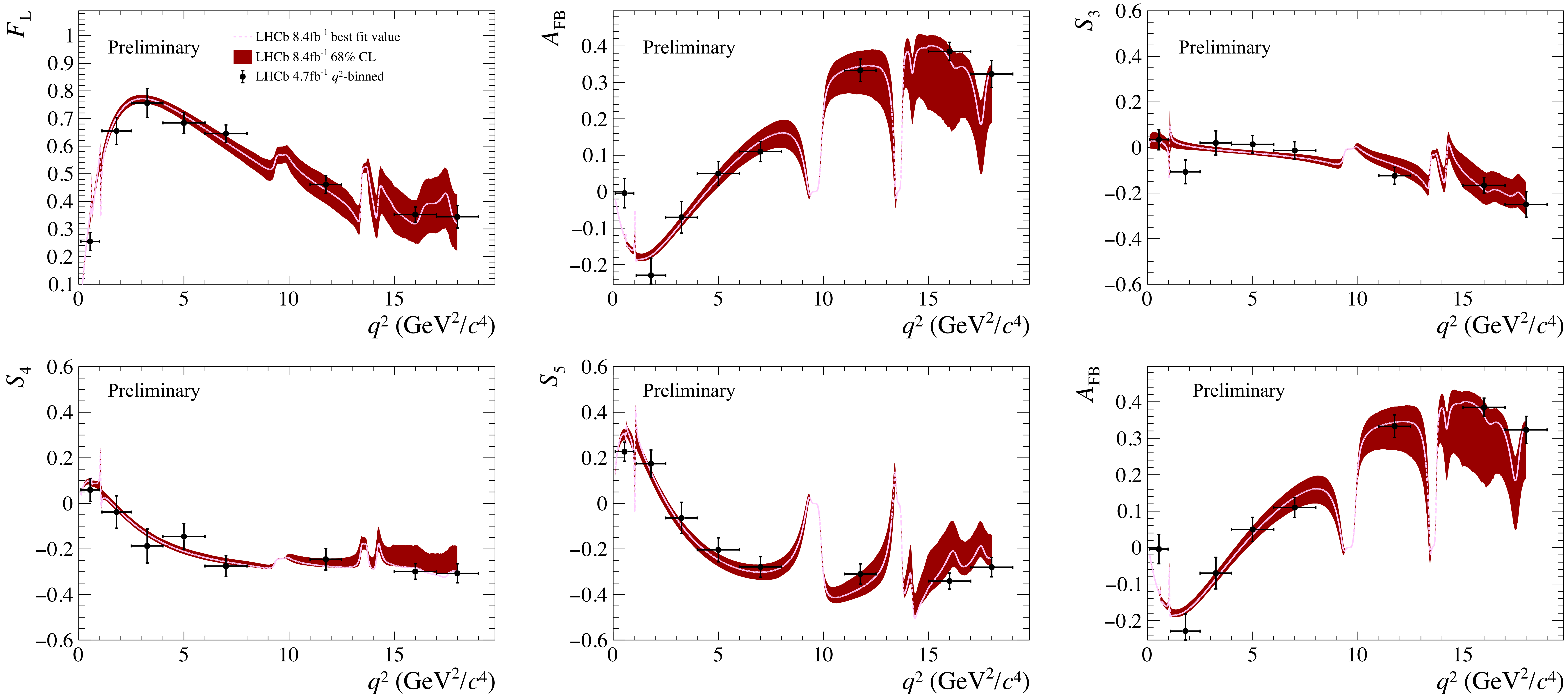
Dispersion relation should be independent of subtraction point

Varying subtraction point between $q_0^2 = -1\,\text{GeV}^2/c^4$ and $q_0^2 = -10\,\text{GeV}^2/c^4$ leads to variation of 35% σ_{stat} in C_9

New

Comparison to binned analysis

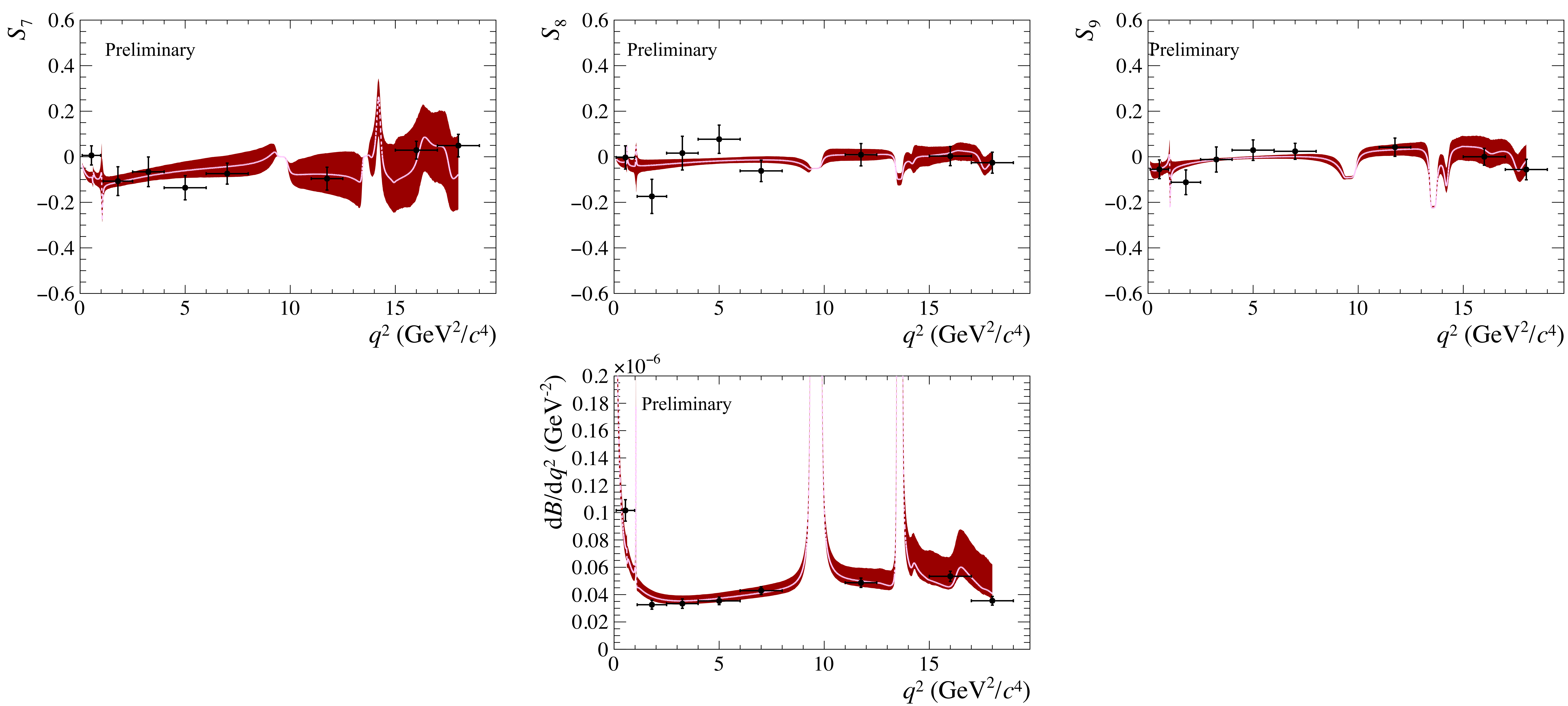
[LHCb-PAPER-2020-002]



Comparison to binned analysis

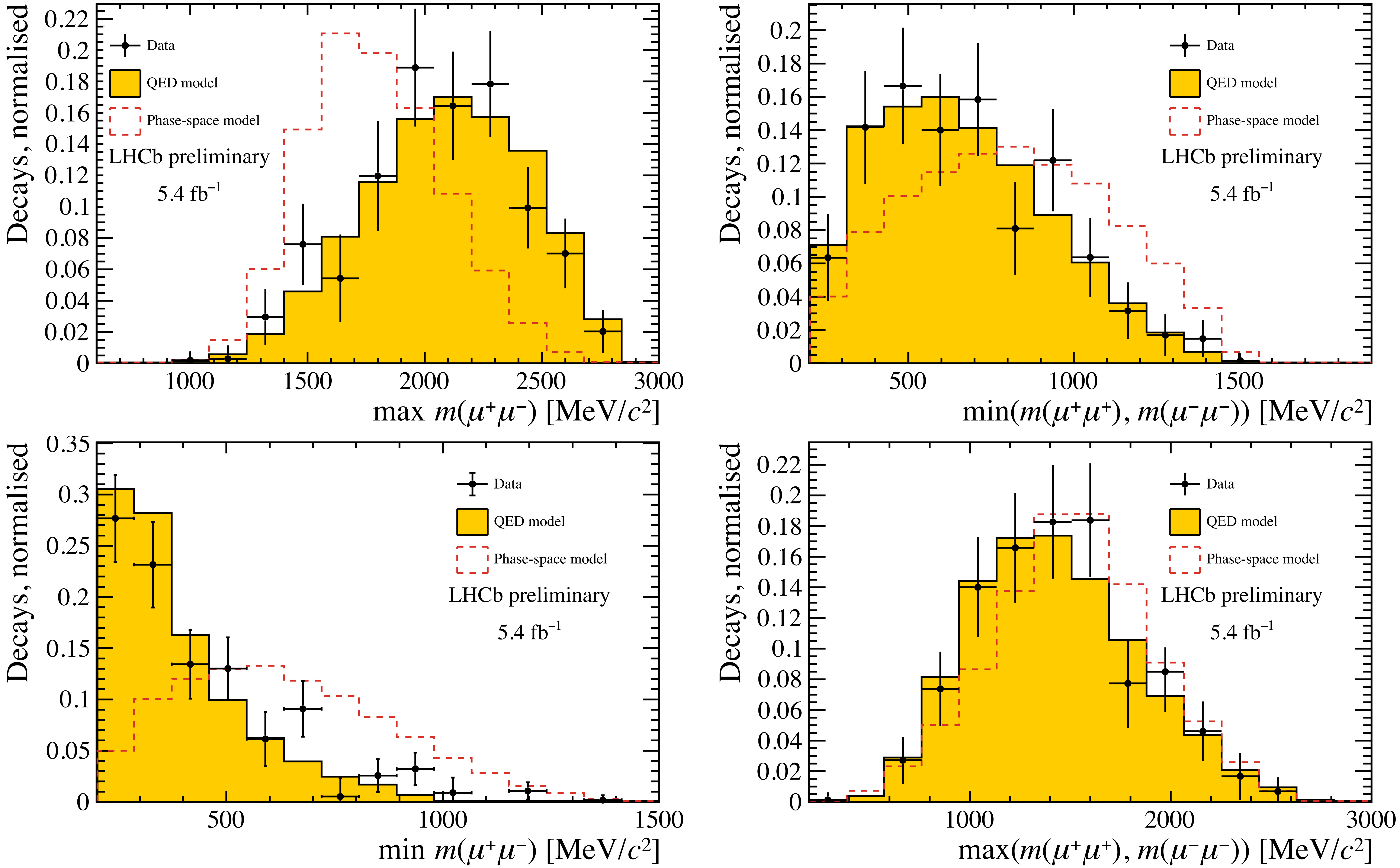
LHCb-PAPER-2024-011,
in preparation

[LHCb-PAPER-2020-002]



QED model

sPlot method is used to study kinematic distributions



Result comparison