Rare and semi-leptonic decays at LHCb

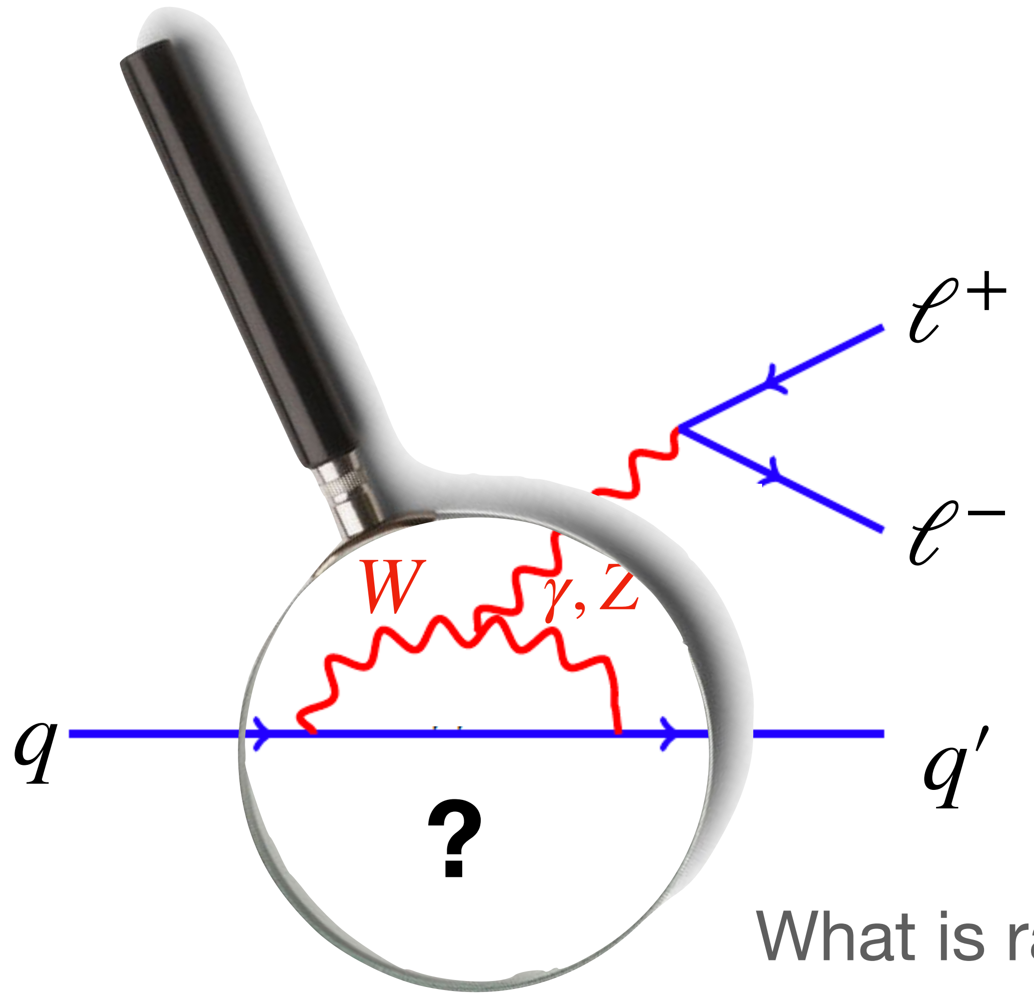
Dominik Mitzel
TU Dortmund
On behalf of the LHCb collaboration

Les Rencontres de Physique de la Vallée d'Aoste 2025

FSP LHCb
Erforschung von Universum und Materie

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Search for NP in rare decays



What is rare?
$\mathscr{B} < 10^{-6}$

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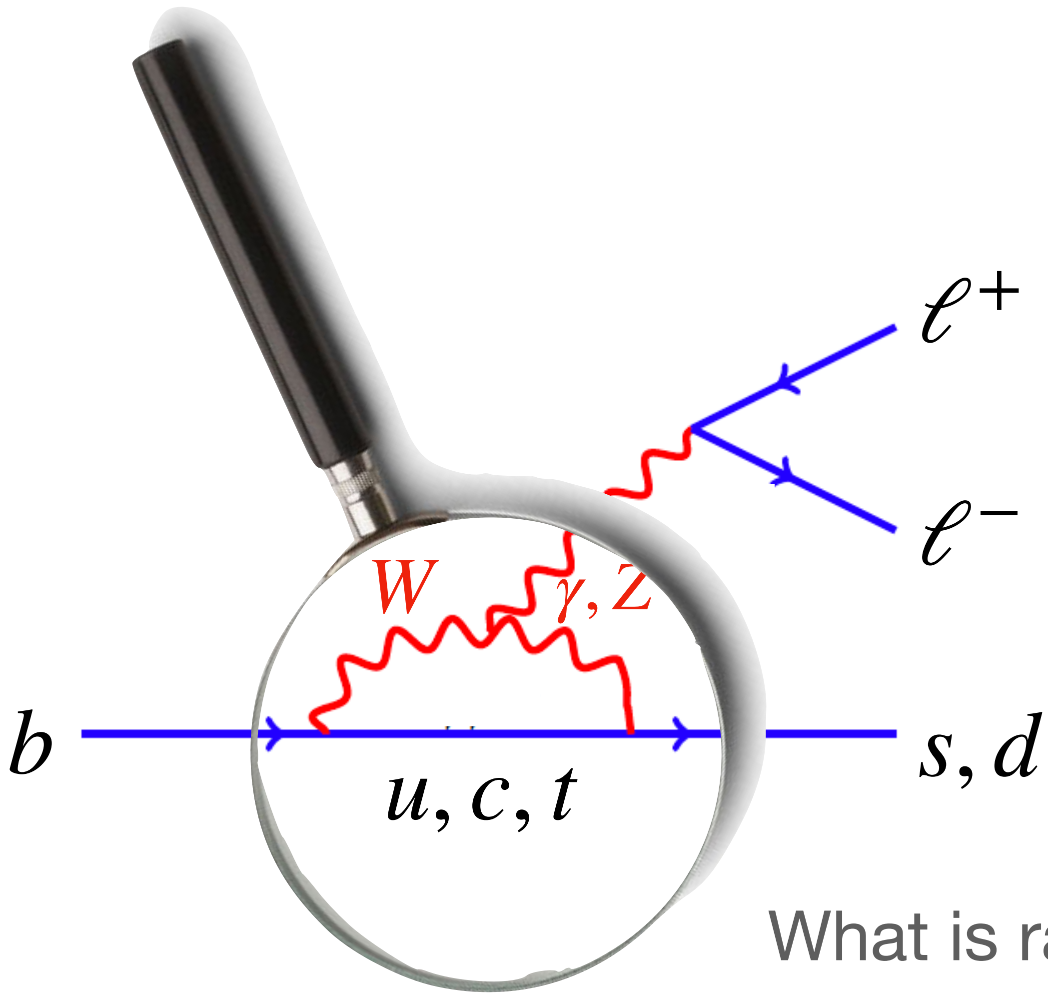

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B-physics: $b \to s\ell^+\ell^-$, $b \to d\ell^+\ell^-$ e.g. $\overline{B}_s(b\bar{s}) \to \phi(s\bar{s})e^+e^-$

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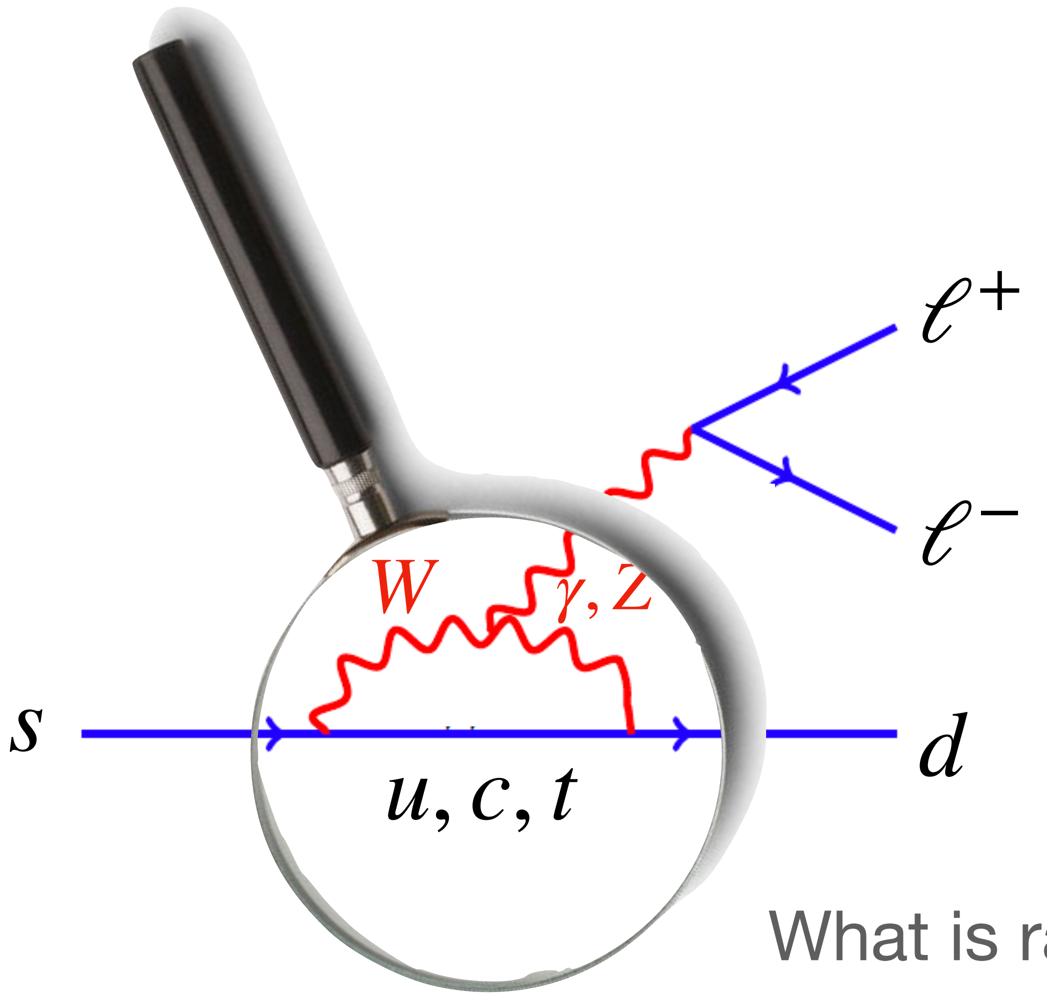

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Kaon-physics: $s \to d\ell^+\ell^-$ e.g. $K^0(\bar{s}d) \to \mu^+\mu^-$

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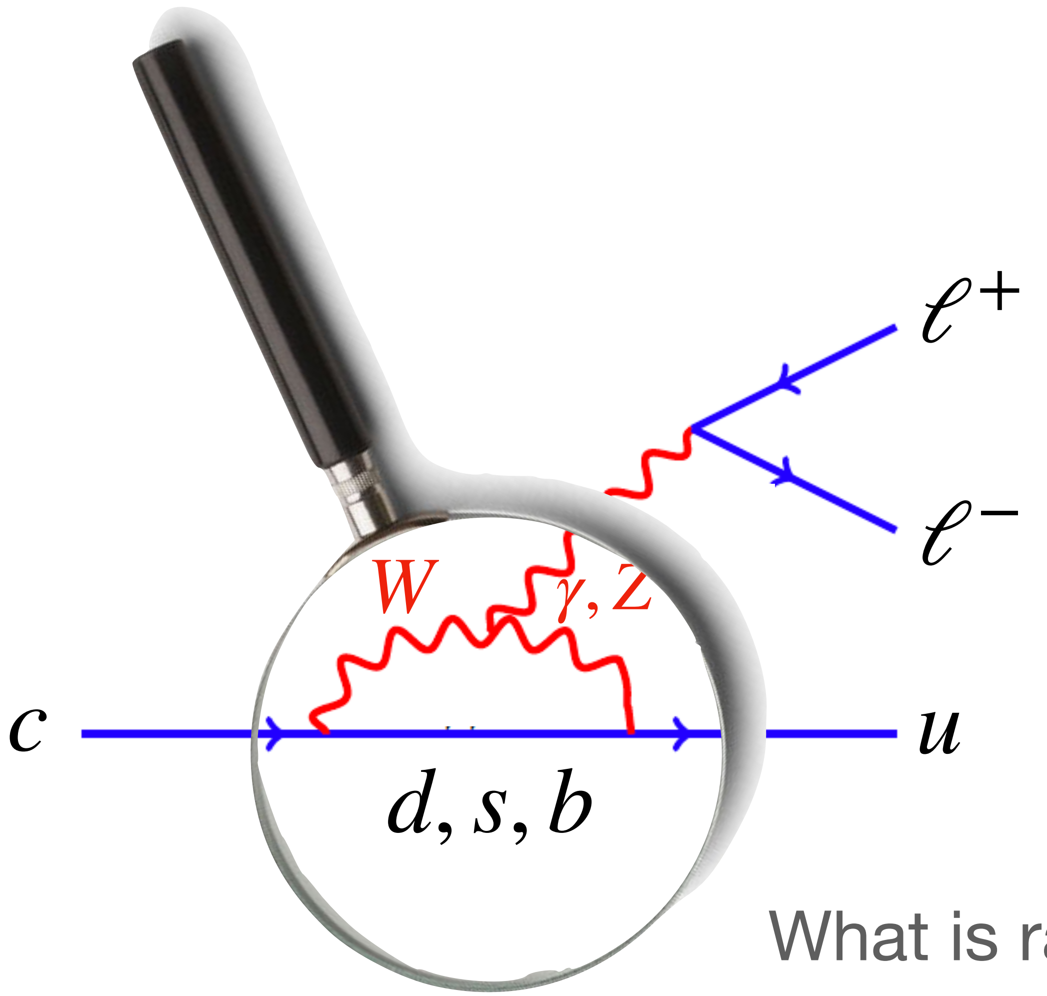

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Charm-physics: $c \to u\ell^+\ell^-$ e.g. $\Lambda_c(cud) \to p(uud)\mu^+\mu^-$

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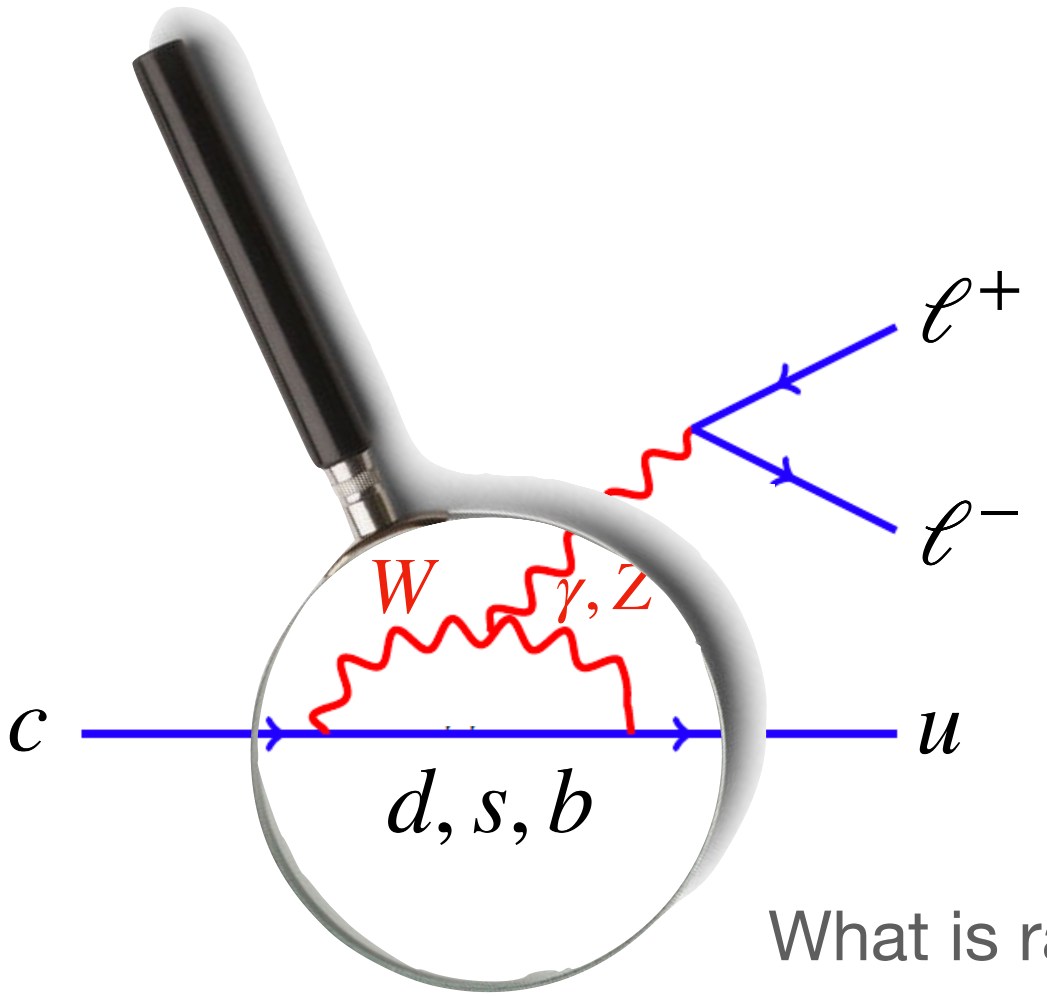

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Today!
(+ $b \to c\ell\nu$)

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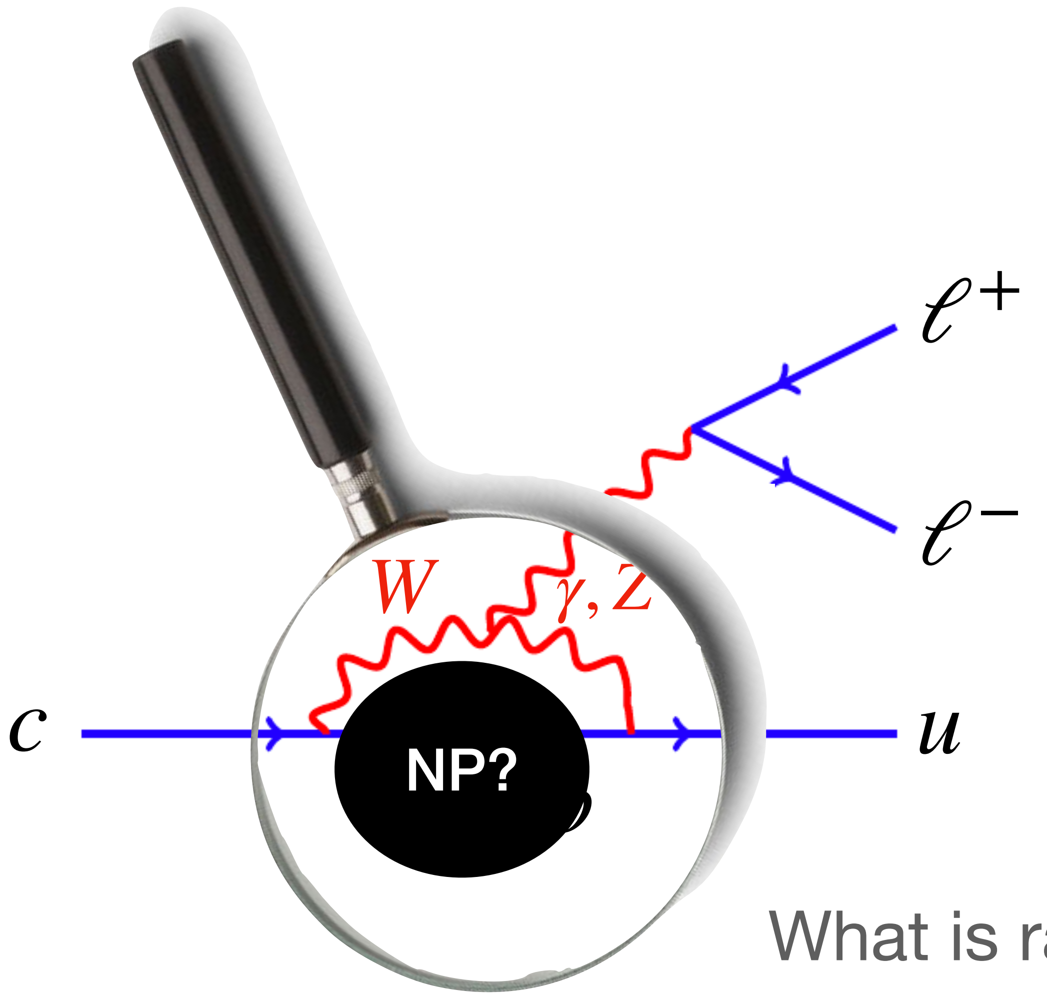

Sensitive to tiny contributions of heavy (>multi TeV) BSM particles!

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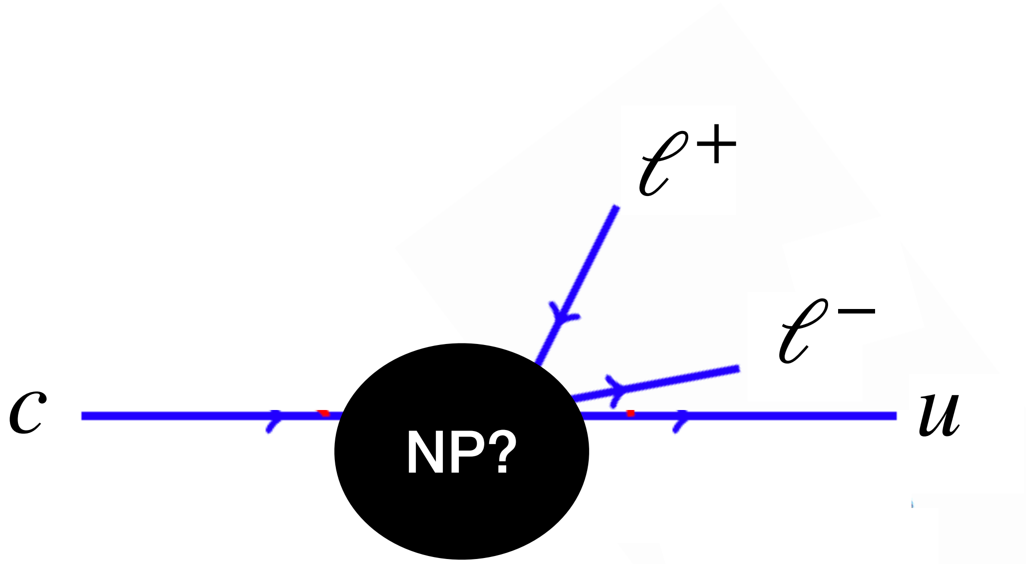
Effective description:



$C_7^{(\prime)}, C_{9,10}^{(\prime)}$
'Wilson Coefficients '

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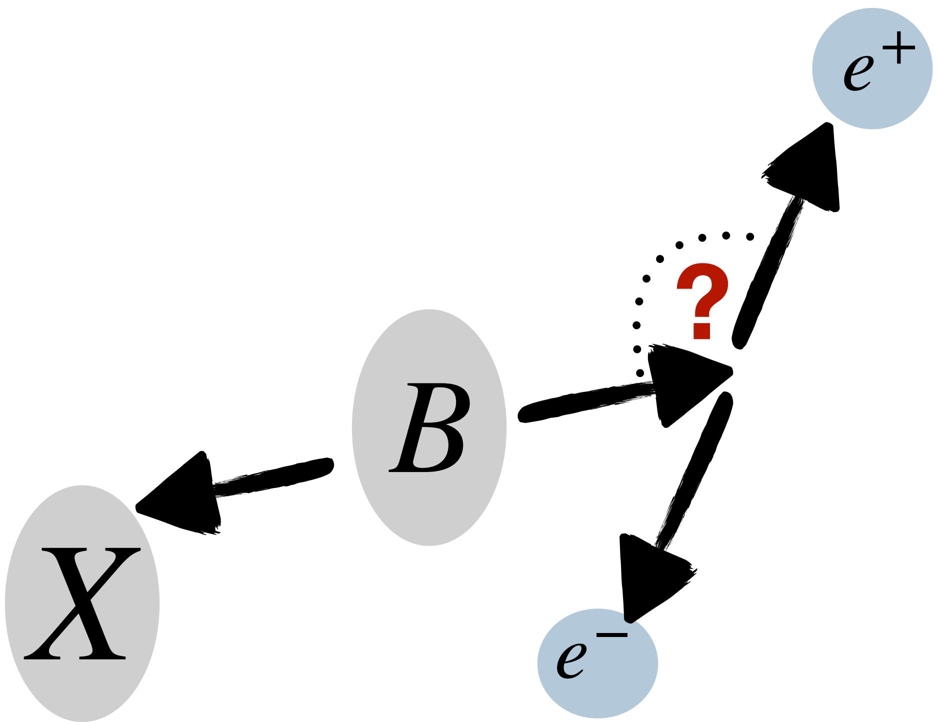

- Angular analyses

~ Lorentz-Structure $\overline{\psi}\Gamma_{NP}\psi$

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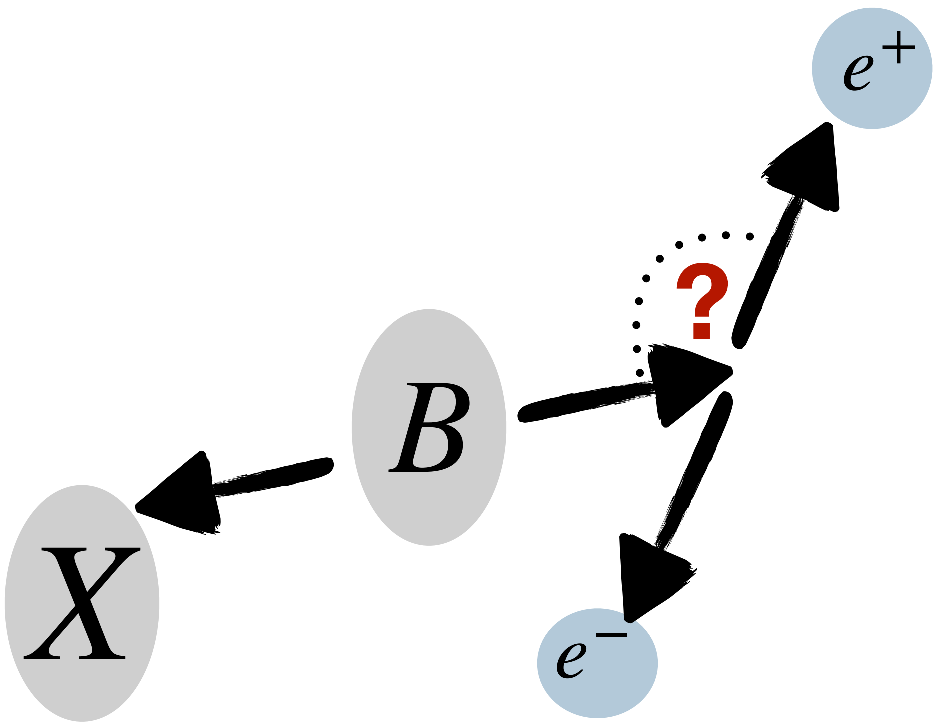

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- Angular analysis of $B^0 \to K^{*0} e^+ e^+$ arXiv:2502.10291
- Photon polarisation in b → sγ transitions using $B_s^0 \to \phi e^+ e^-$ arXiv:2411.10219

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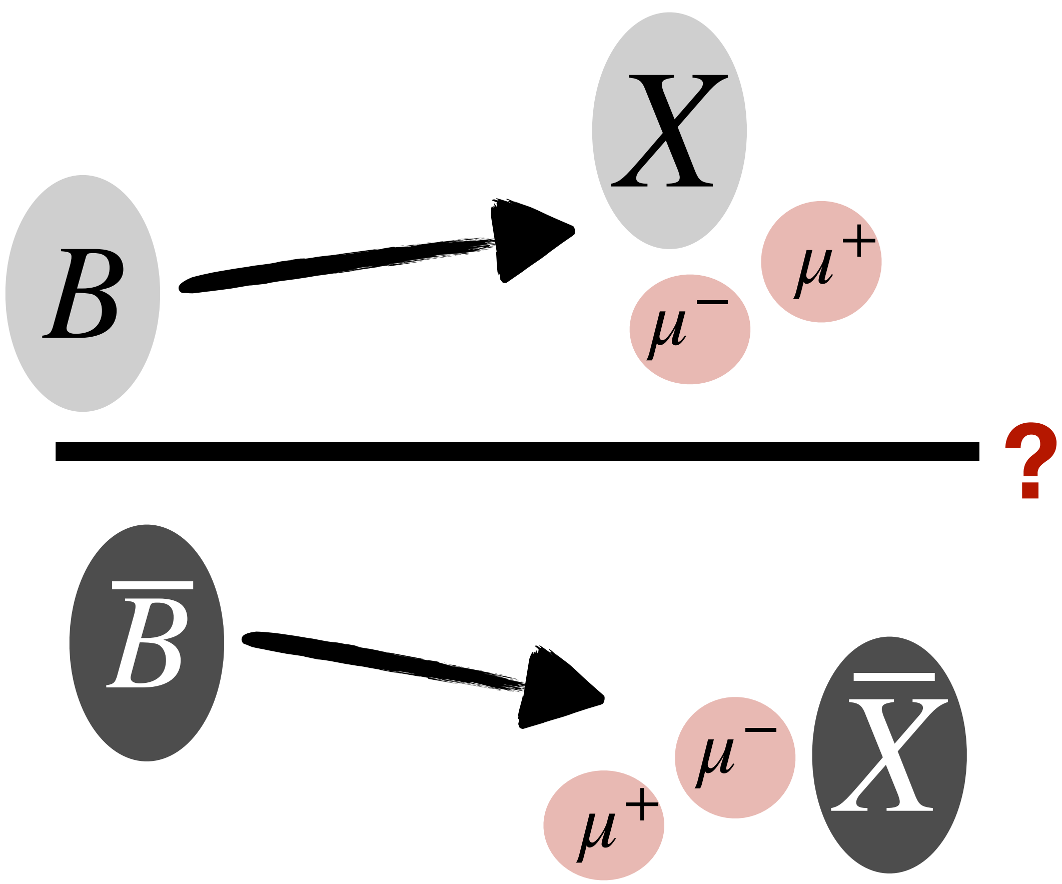

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- CP and angular asymmetries in $\Lambda_c \to p\mu^+\mu^-$ arXiv:2502.04013

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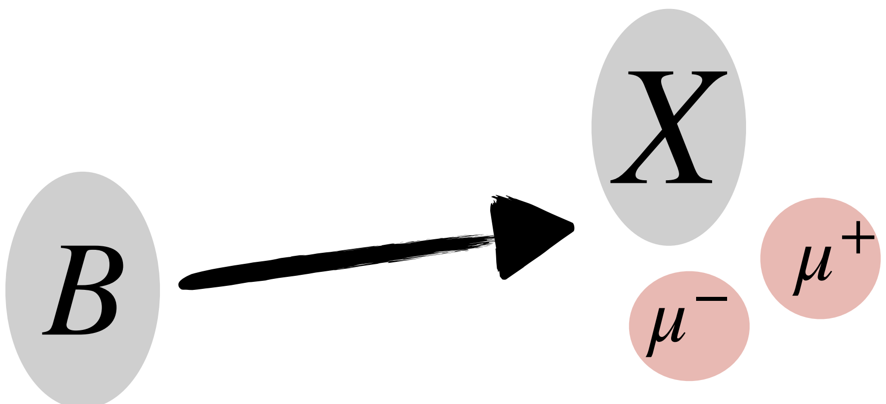

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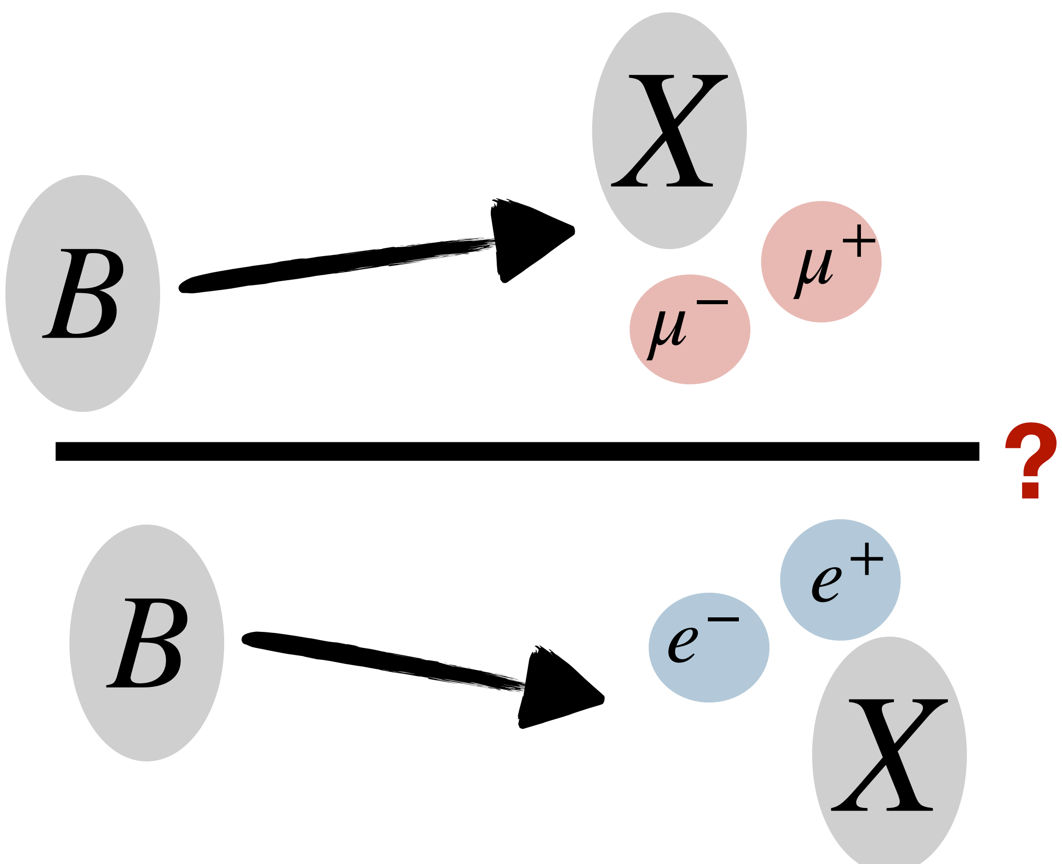

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Possible difference muons/electrons/taus ?

- Lepton flavour universality with $B^+ \to K^+\pi^+\pi^-\ell^+\ell^+$, [arXiv:2412.11645] $B^+ \to K^+\ell^+\ell^-$ LHCb-PAPER-2024-056
- Search for $D^0 \to \pi^+\pi^-e^+e^-$ and $D^0 \to K^+K^-e^+e^-$ arXiv:2412.09414

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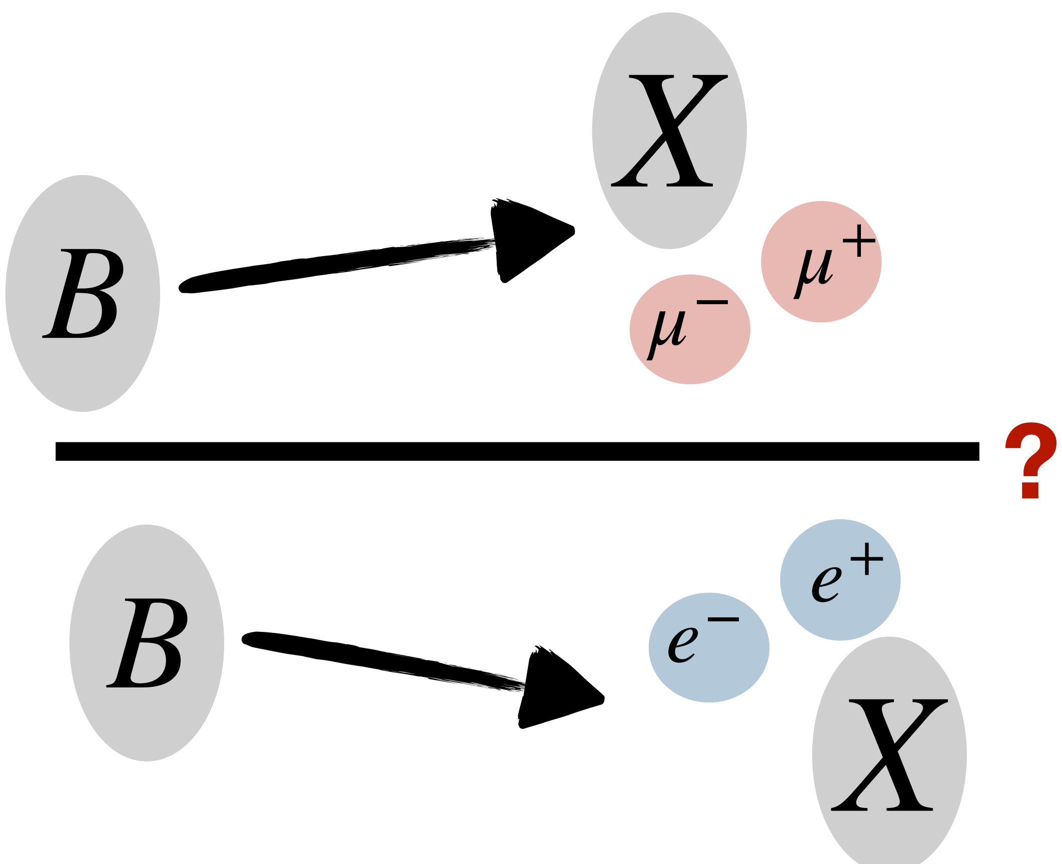

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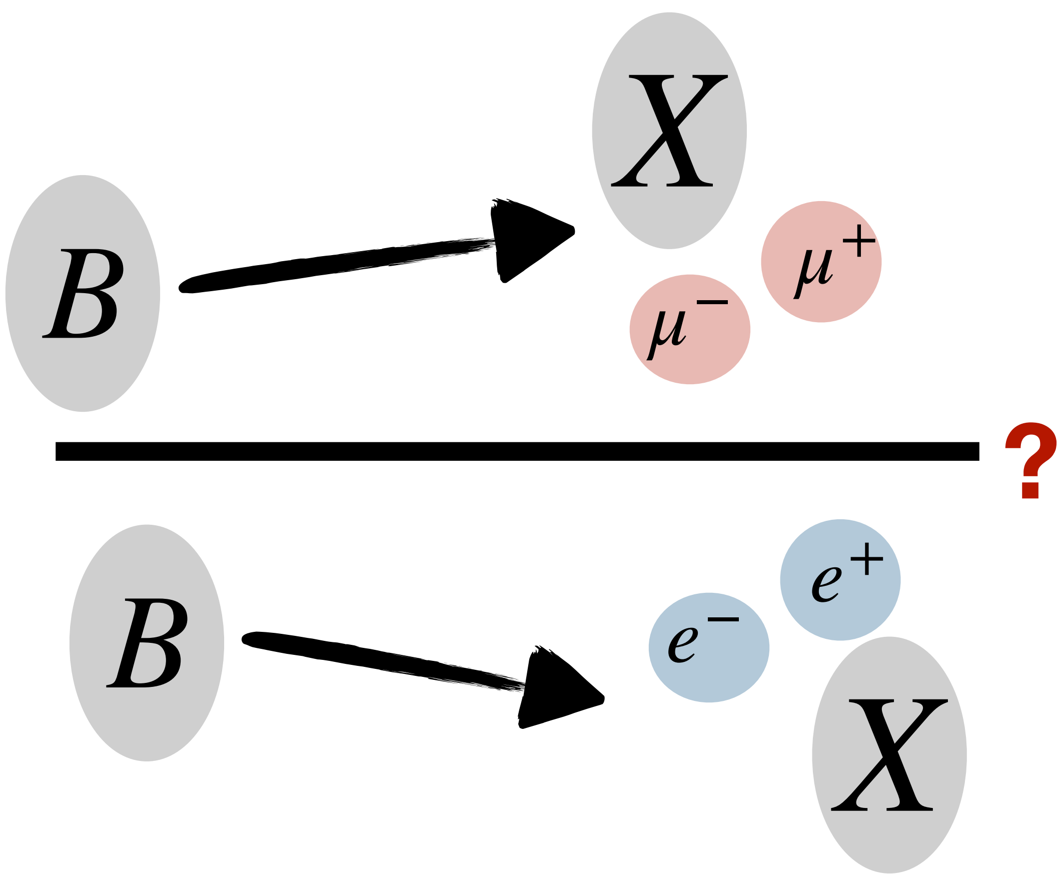
- Evidence for the decay $B \to D^{**}\tau\nu$ arXiv:2501.14943

Today's program

More RD@LHCb: see also Davide's talk tomorrow!



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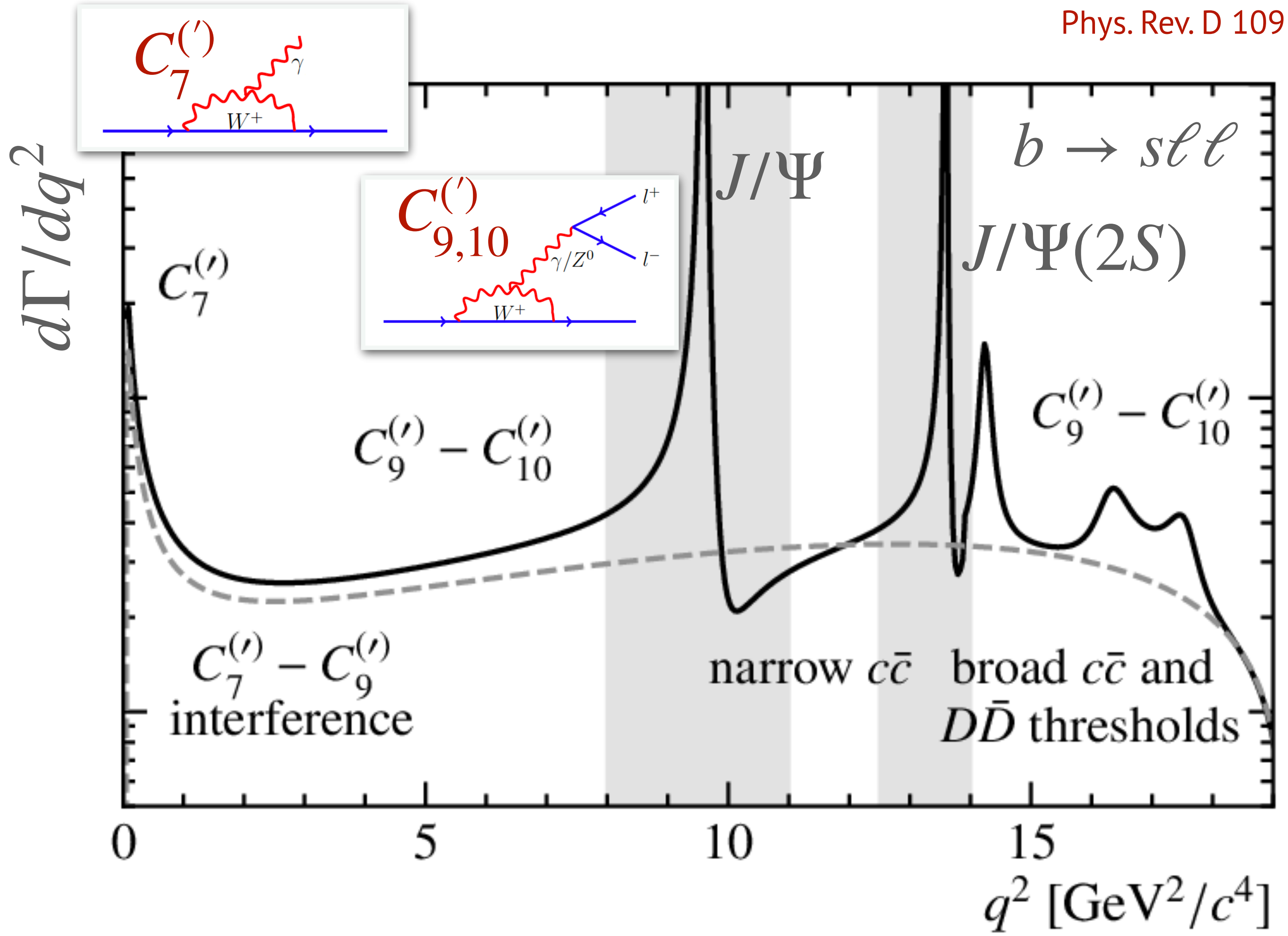
Phys. Rev. D 109 (2024) 052009



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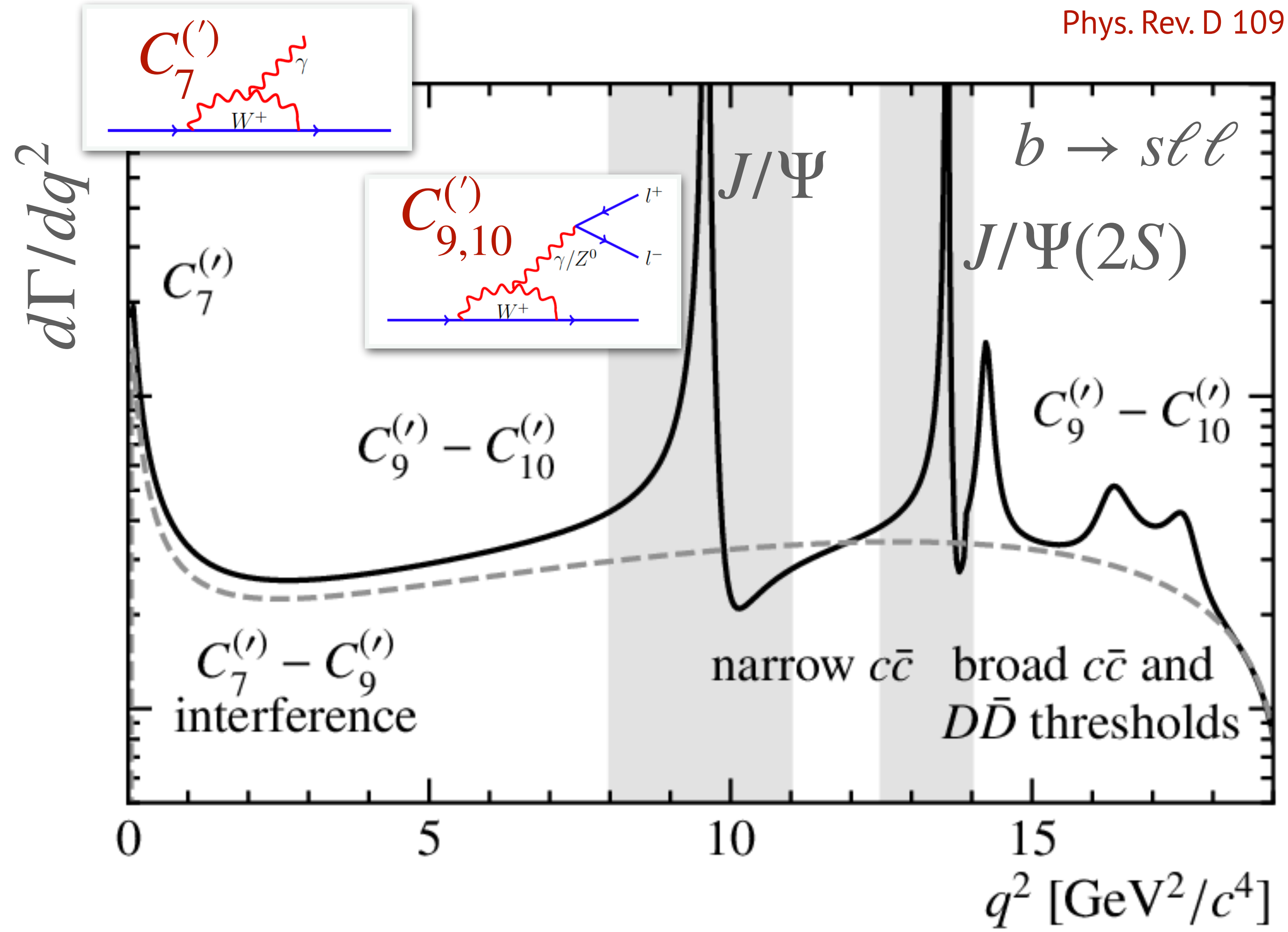

- In Charm: Phase space smaller and dominated by resonances

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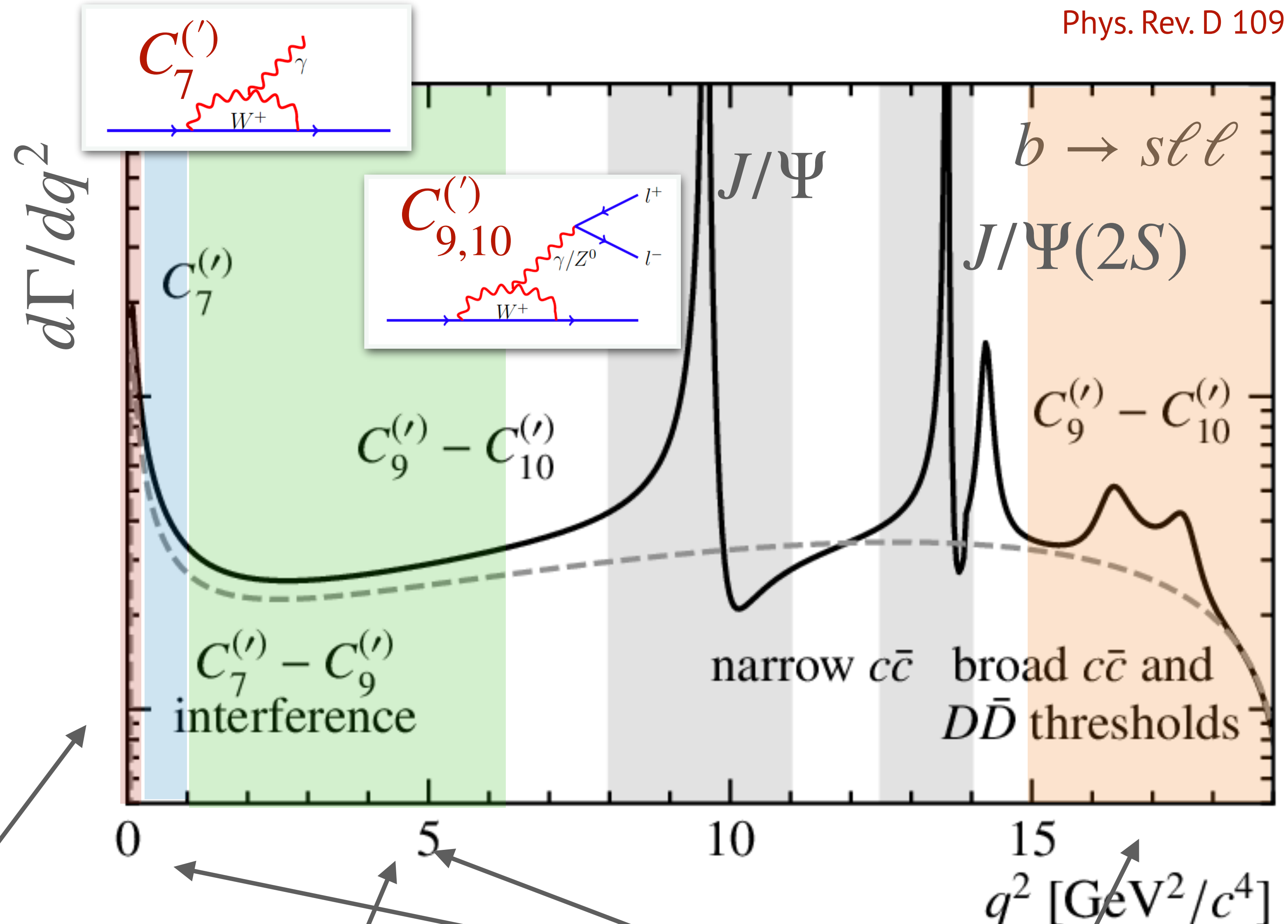
Phys. Rev. D 109 (2024) 052009



arXiv:2411.10219

arXiv:2410.13748

LHCb-PAPER-2024-056
In preparation

arXiv:2502.10291 arXiv:2412.11645

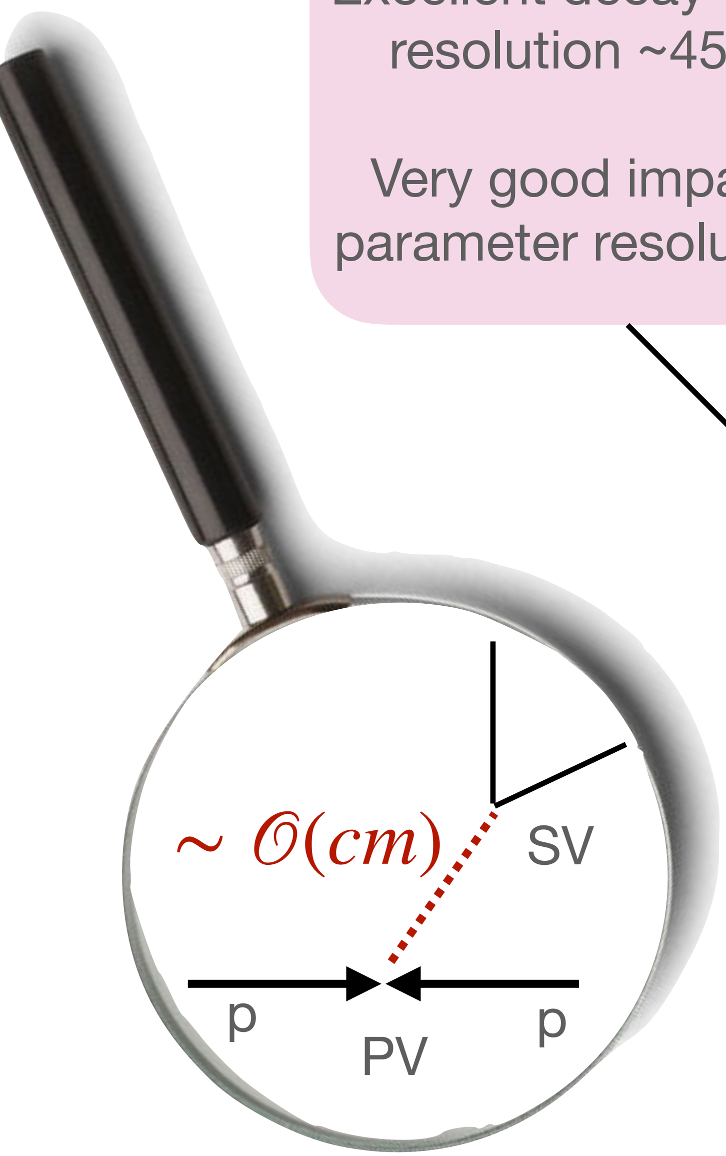
The Run I/II LHCb detector

JINST3(2008)S08005
Int.J.Mod.Phys.A30(2015)no.07 1530022

Vertexing

Excellent decay-time resolution ~45fs

Very good impact parameter resolution

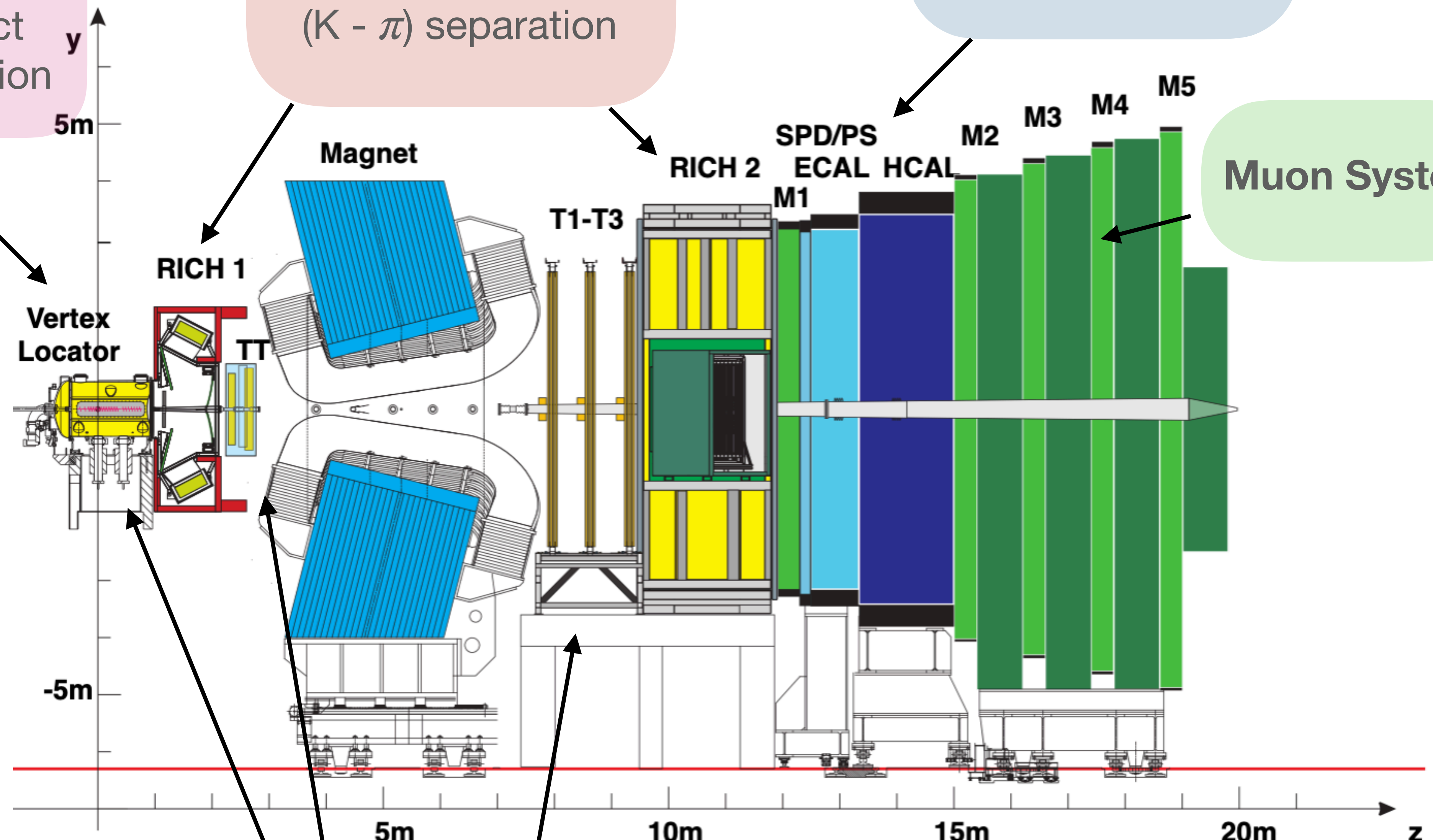


Excellent particle Identification

(K - π) separation

Calorimetry

Muon System



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very good momentum resolution $\delta p/p \sim 0.5 - 1\,\%$

Real-time analysis, alignment & calibration (2015-2018)

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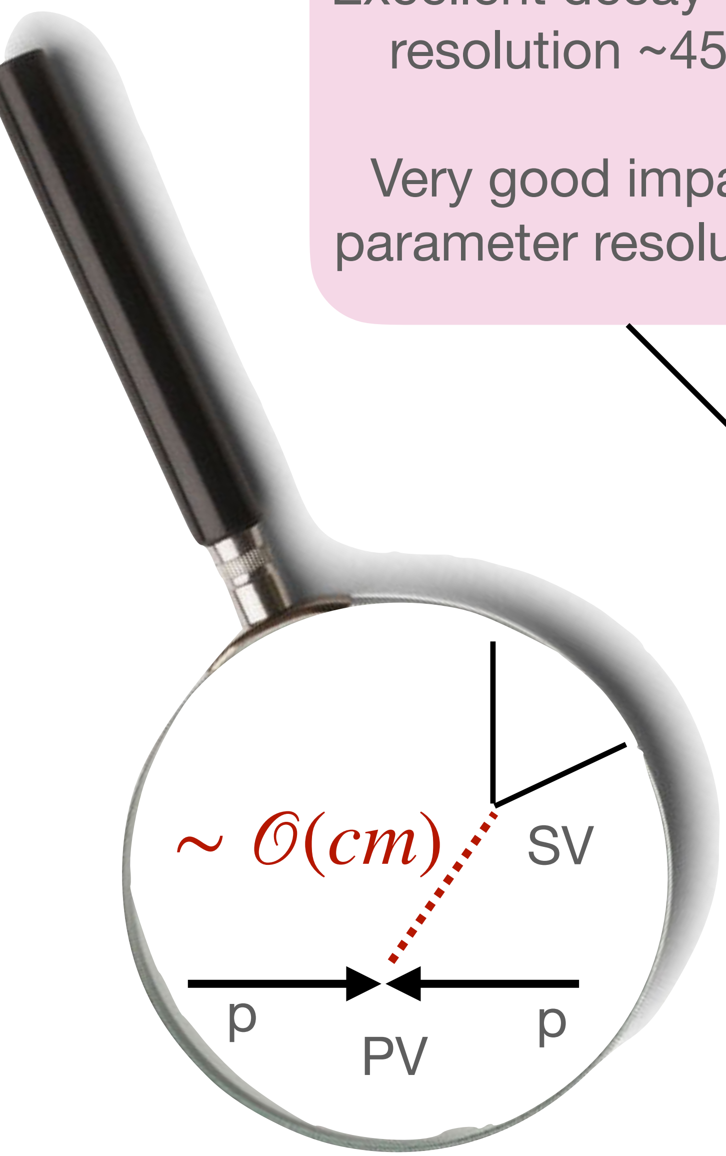

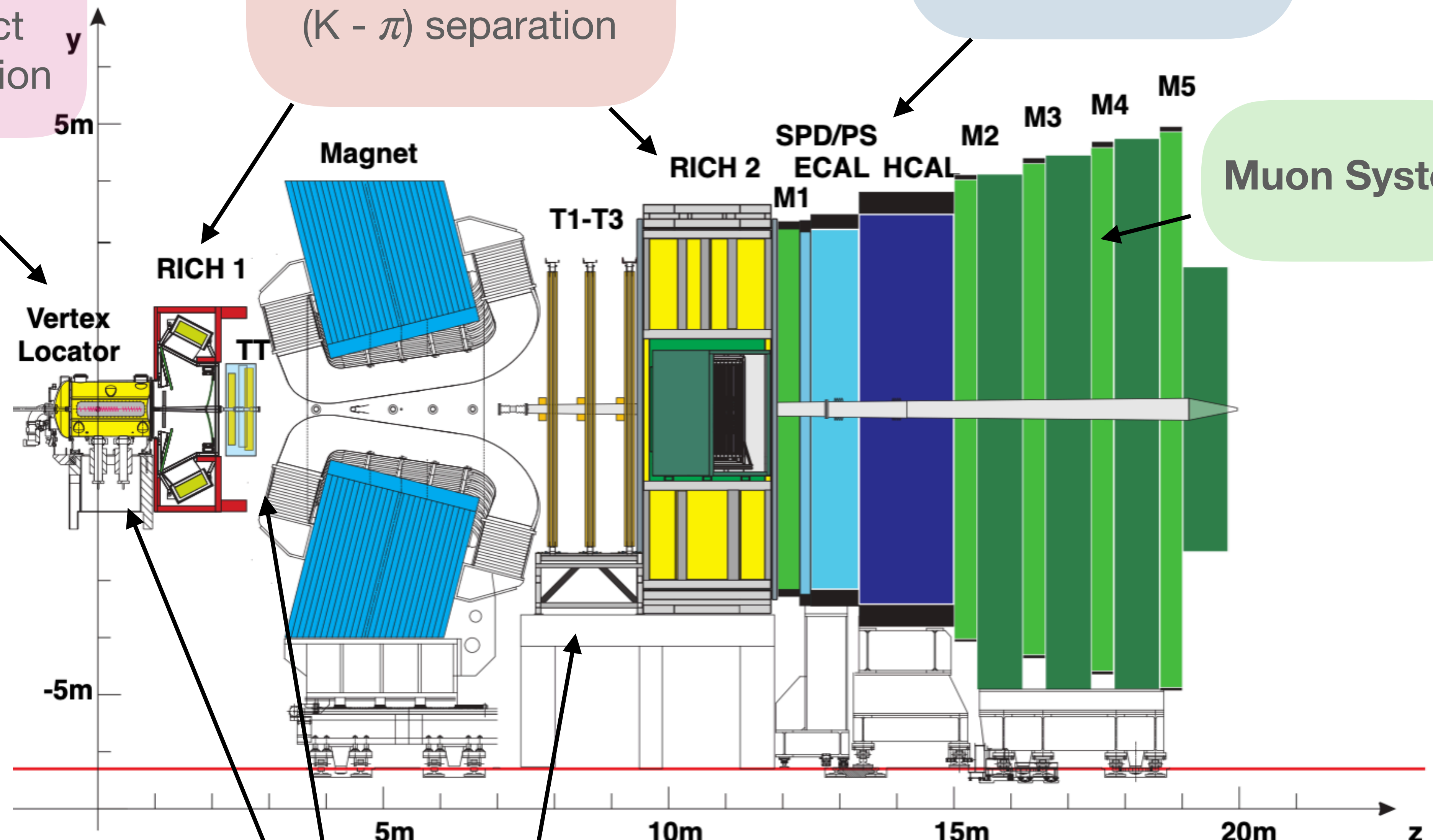

Today: Results using RunI/RunII data

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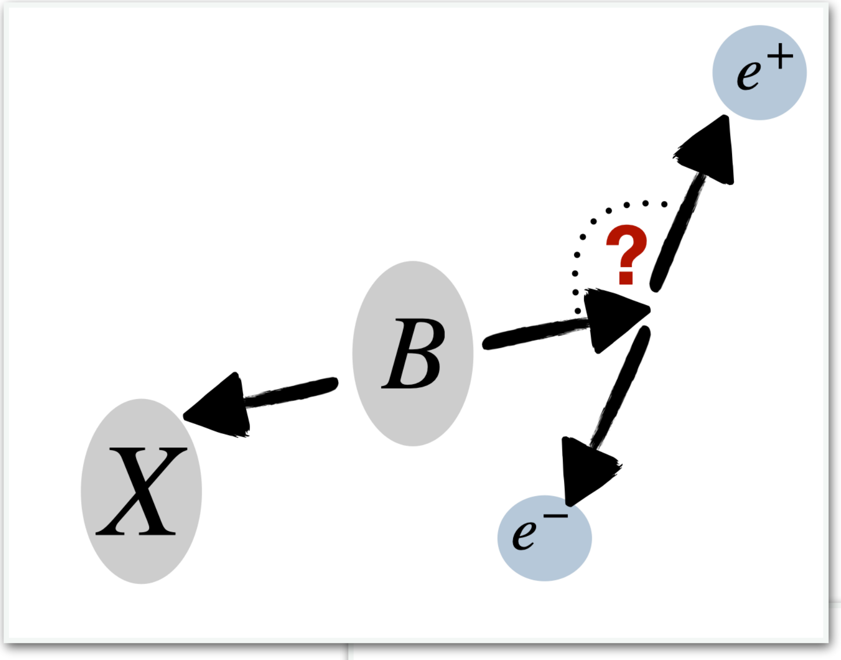
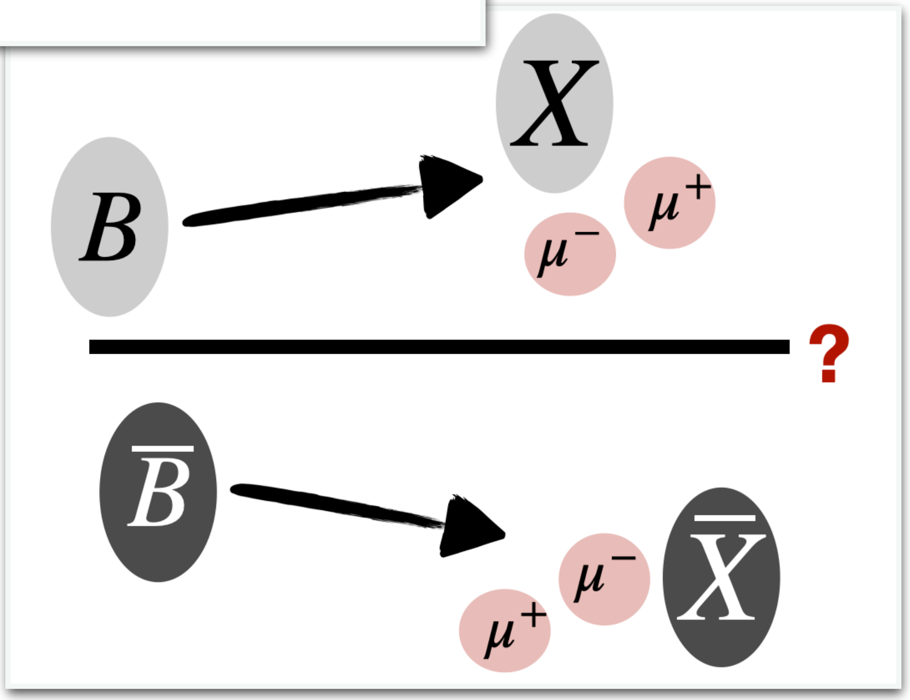
Real-time analysis, alignment & calibration (2015-2018)

Angular analyses & CPV

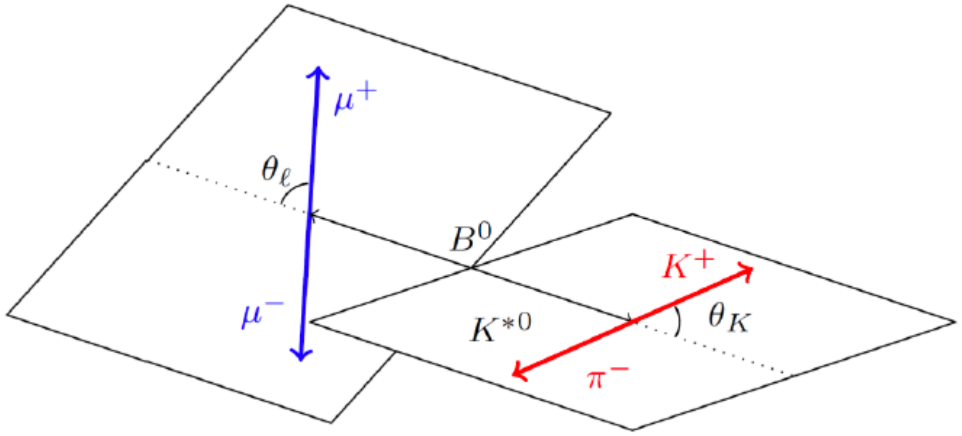




Angular analysis $B^0 \to K^{*0}\ell^+\ell^-$

- Measurement of angular observables

$$\frac{1}{\frac{\mathrm{d}(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2}}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\left[\sum_i J_i(q^2)c_i(\Omega)\right]$$



Coefficients sensitive to $C_{7,9,10}$
(+ hadronic parameters)

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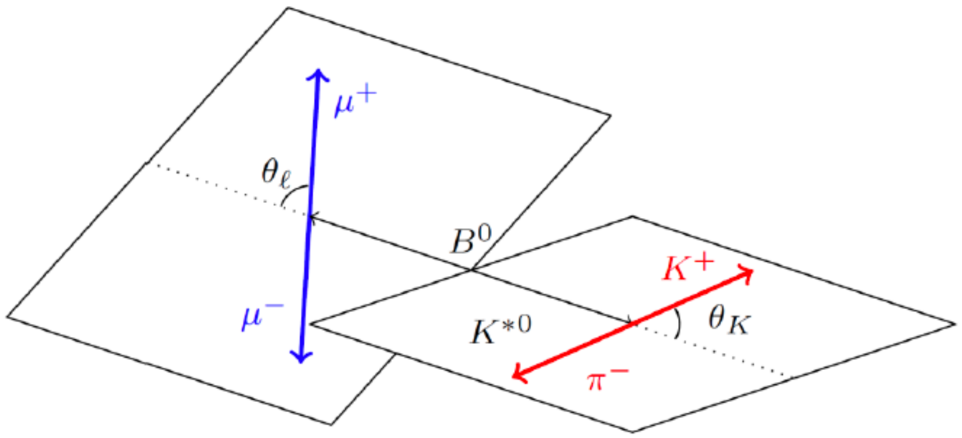
$$\frac{1}{\frac{d(\Gamma+\bar{\Gamma})}{dq^2}}\frac{d^4(\Gamma+\bar{\Gamma})}{dq^2\,d\vec{\Omega}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + \frac{4}{3}A_{\rm FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$



Often optimised 'P_i' observables

$$P_1 = \frac{2S_3}{(1-F_{\rm L})}, \quad P_2 = \frac{2}{3}\frac{A_{\rm FB}}{(1-F_{\rm L})}, \quad P_3 = \frac{-S_9}{(1-F_{\rm L})}, \quad P'_{4,5,6,8} = \frac{S_{4,5,7,8}}{\sqrt{F_{\rm L}(1-F_{\rm L})}}$$

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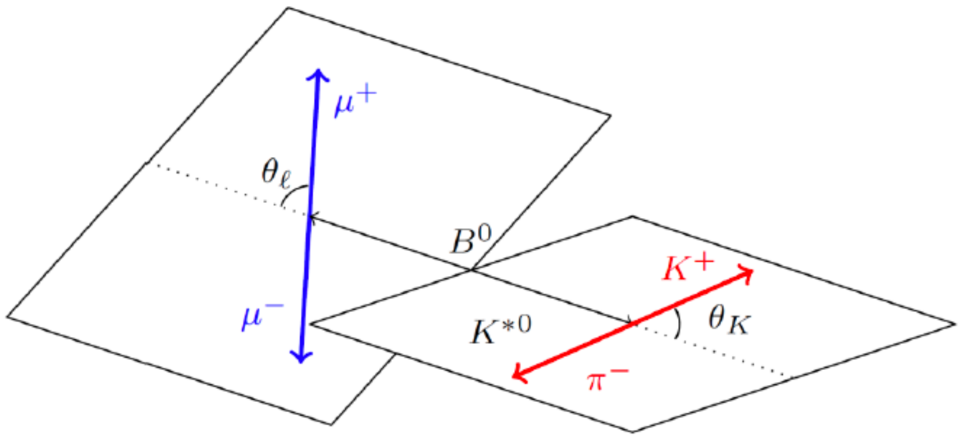

Often optimised 'P_i' observables

- Different approaches for muon mode: Binned angular analyses, model-dependent amplitude analyses, ….

JHEP 09 (2024) 026 Phys. Rev. Lett. 132 (2024) 131801 Phys. Rev. D 109 (2024) 052009

Phys. Rev. Lett. 125 (2020) 011802

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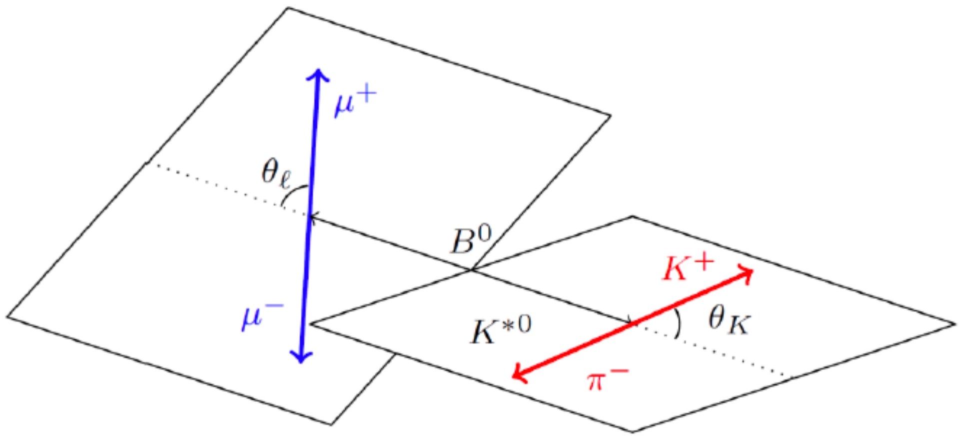

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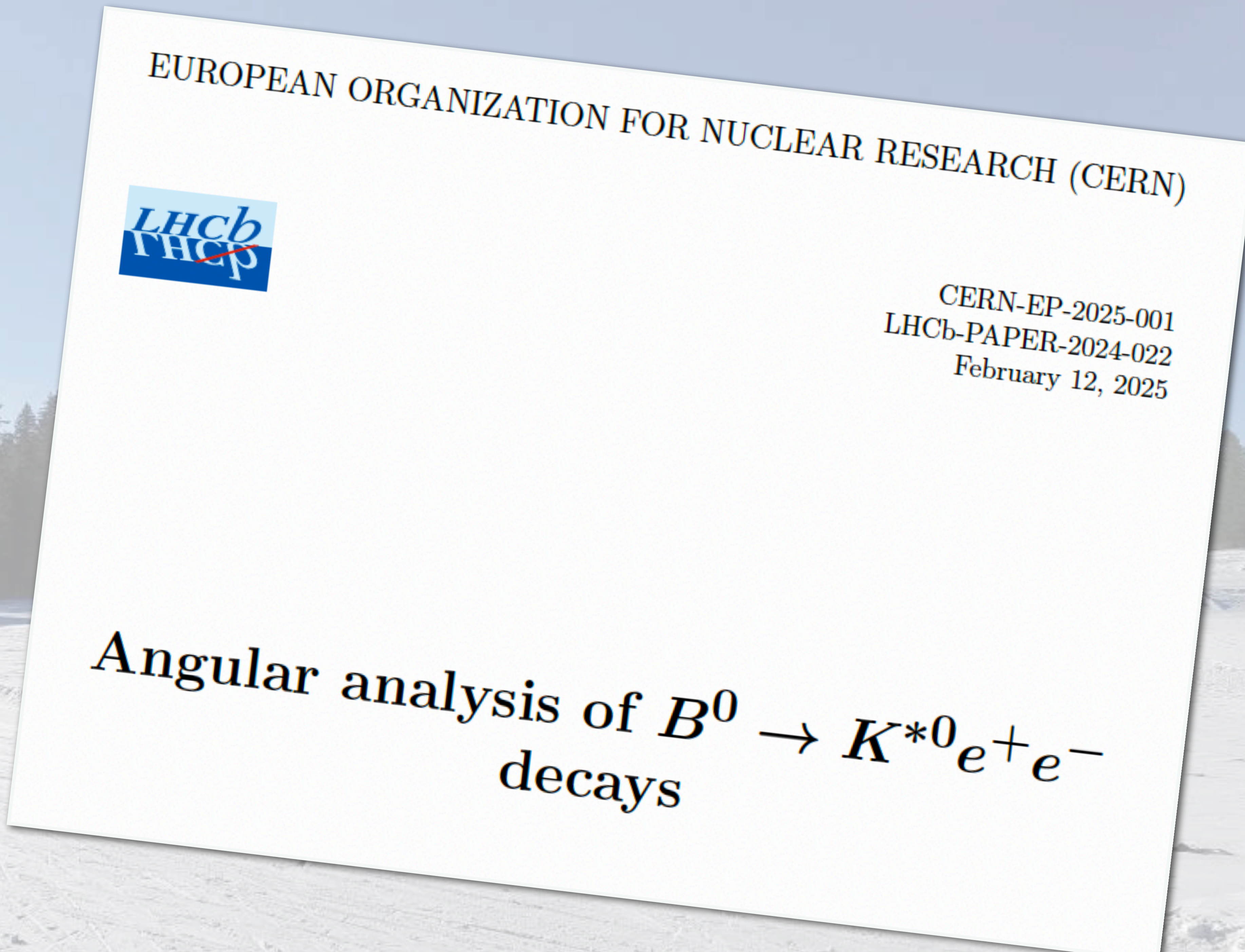
JHEP 09 (2024) 026 Phys. Rev. Lett. 132 (2024) 131801 Phys. Rev. D 109 (2024) 052009

Phys. Rev. Lett. 125 (2020) 011802

Standing tension with SM in vector coupling (C_9). What about dielectron modes?

arXiv:2502.10291



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2025-001
LHCb-PAPER-2024-022
February 12, 2025

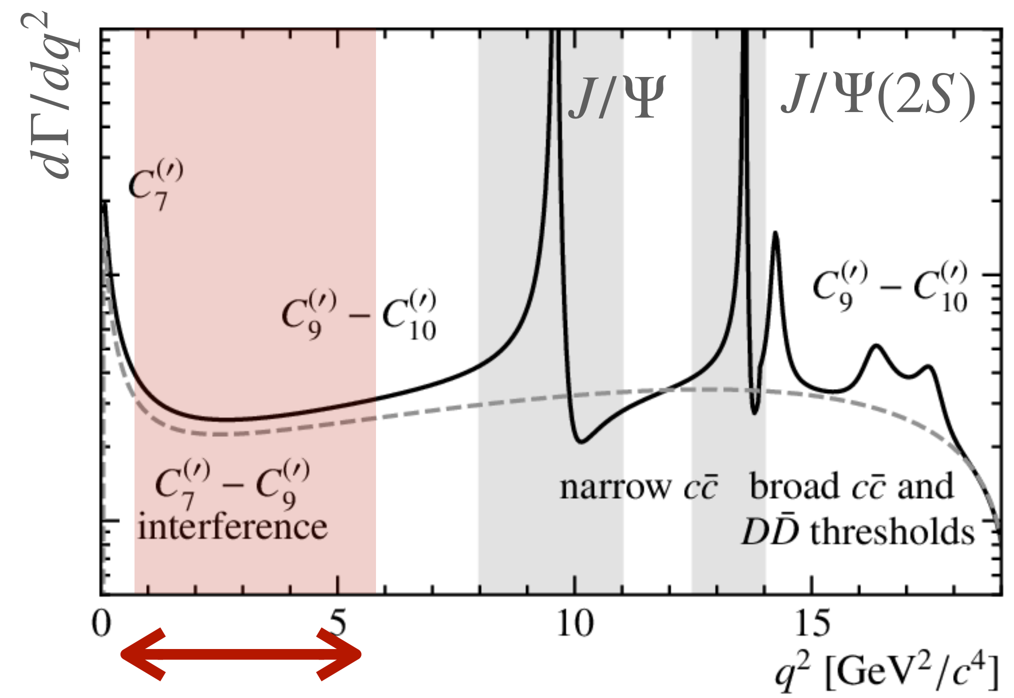
Angular analysis of $B^0 \to K^{*0} e^+ e^-$ decays

Angular analysis $B^0 \to K^{*0}e^+e^-$

arXiv:2502.10291

- Measurement in central q^2 region [1.1,6.0] GeV^2

- Full Run I and Run II data sets (9/fb)



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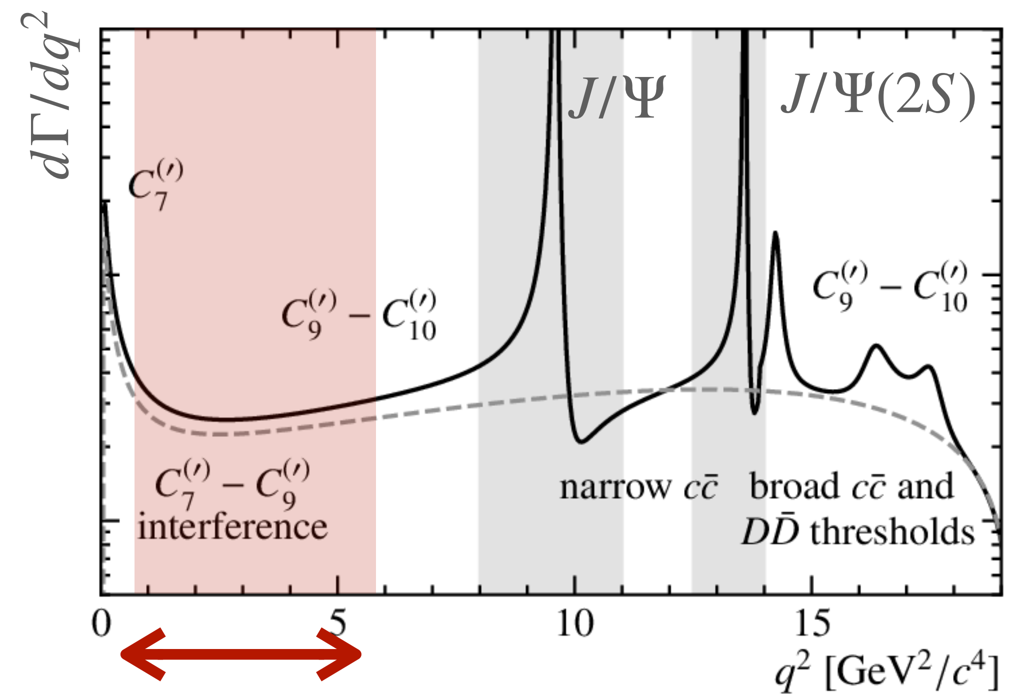
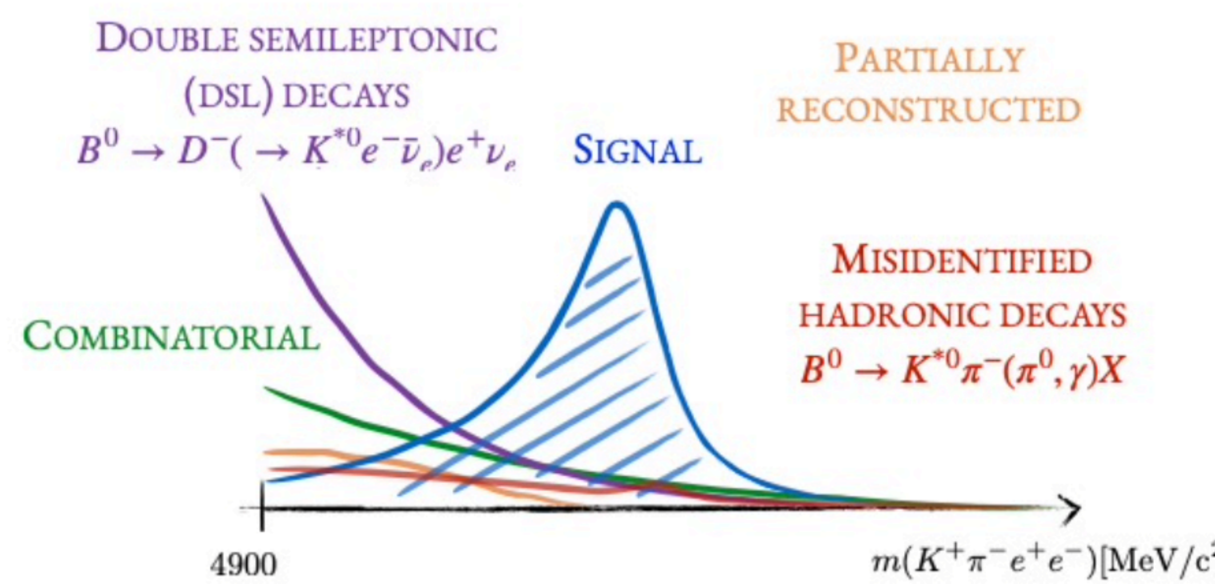
    - Correction for acceptance variations $\epsilon(\cos\theta_l, \cos\theta_K, \phi, q^2)$



M.H. Schune, Talk at rencontres de Blois (2024)



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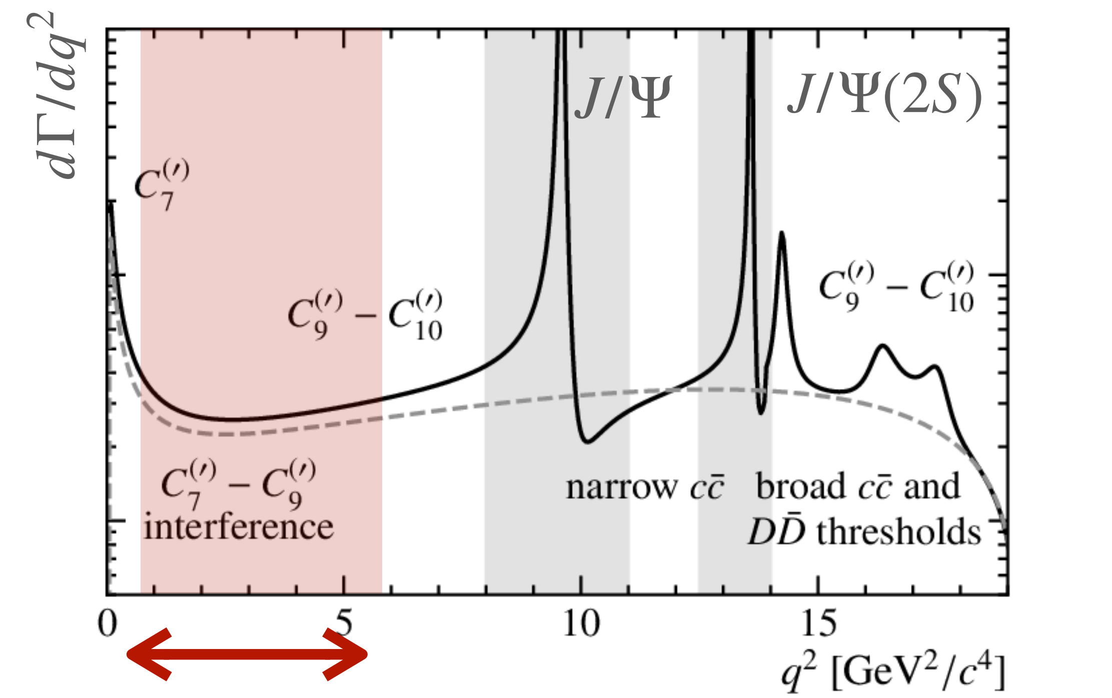
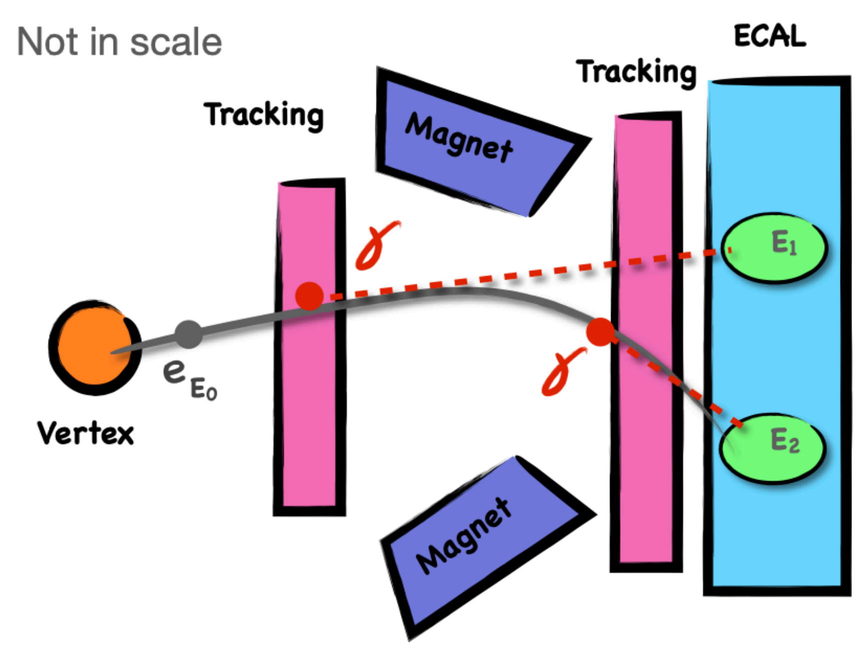
  - Electrons more challenging than muons due to Bremsstrahlung



S. Celani, Talk at LHCb Implications Workshop (2024)



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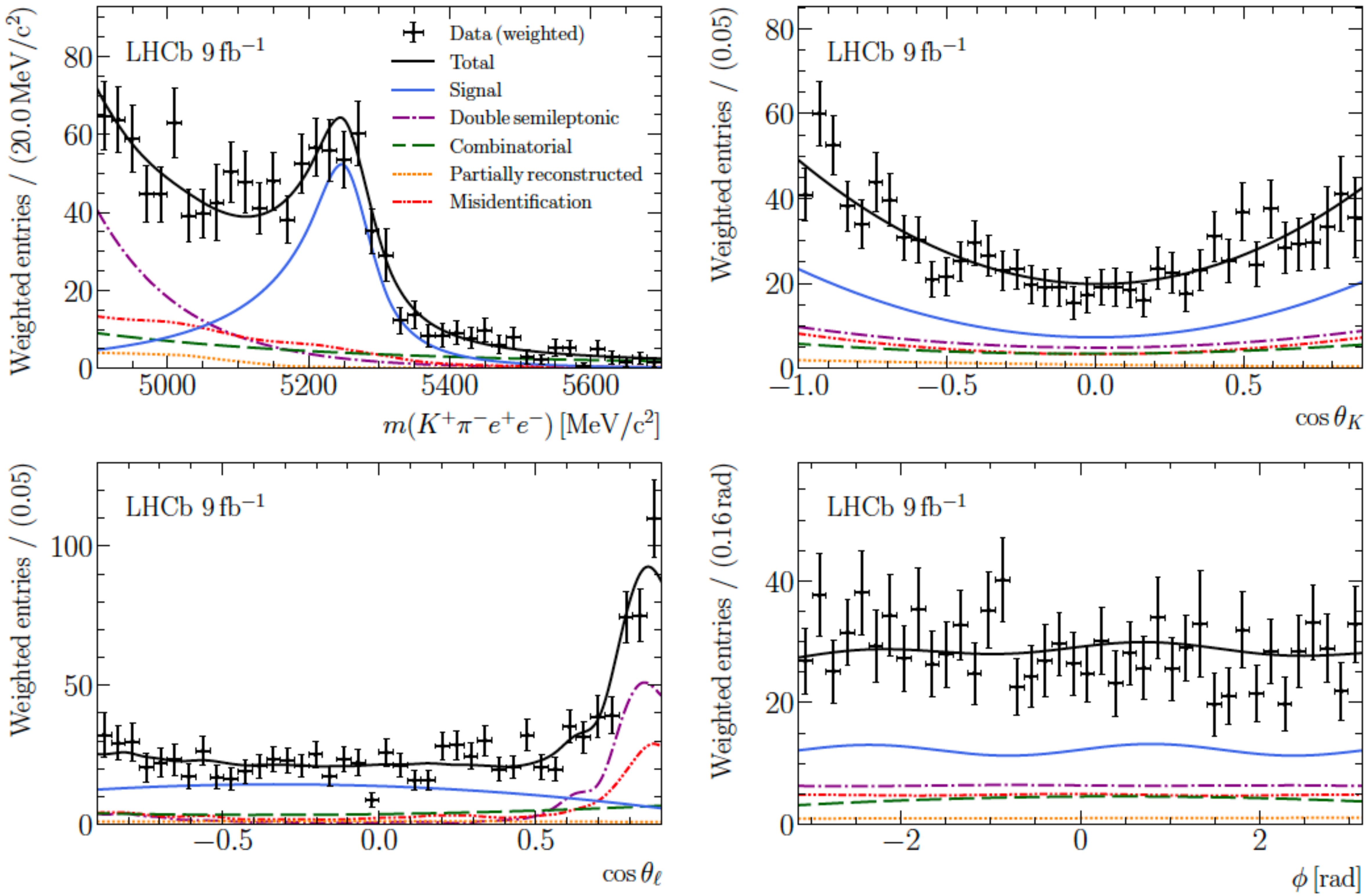
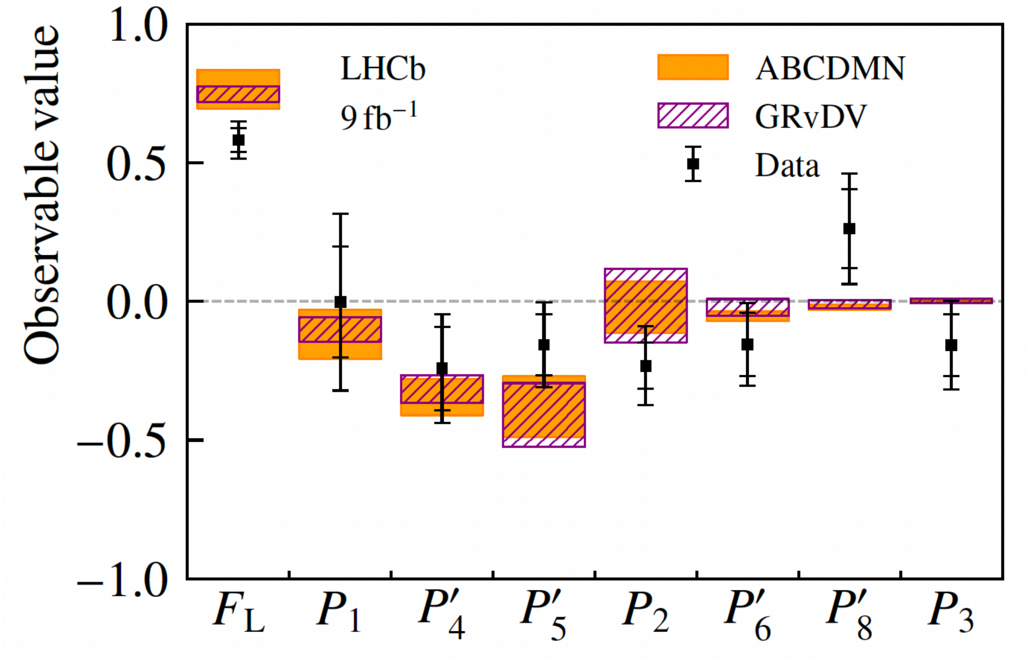


Angular analysis $B^0 \to K^{*0}e^+e^-$

arXiv:2502.10291

Results

- Results consistent with SM prediction
- Most precise measurement of angular observables in $B^0 \to K^{*0}e^+e^-$ in central q^2



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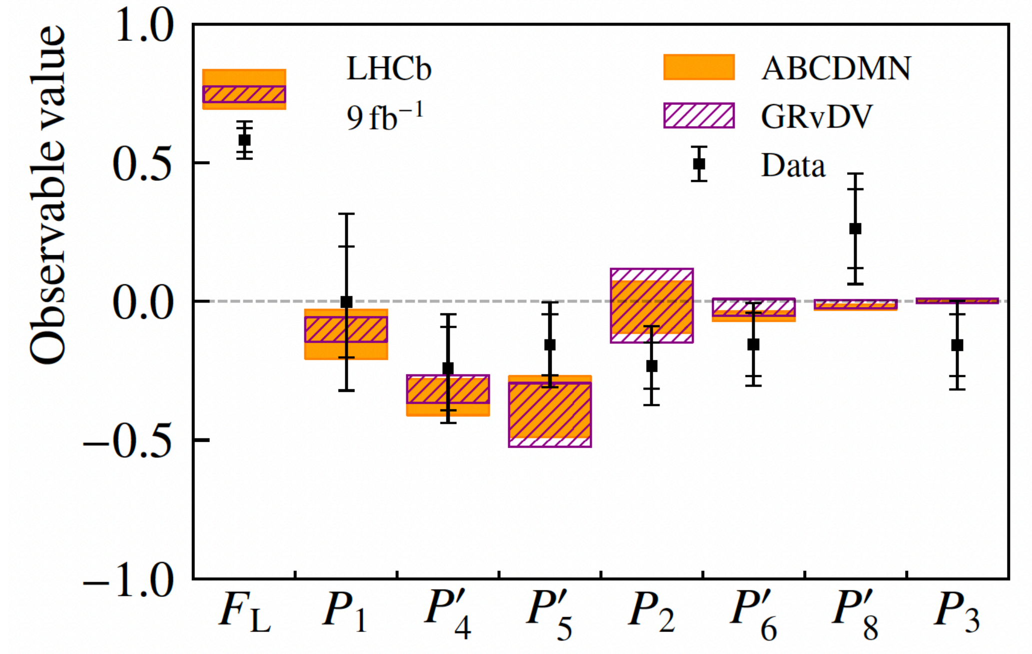
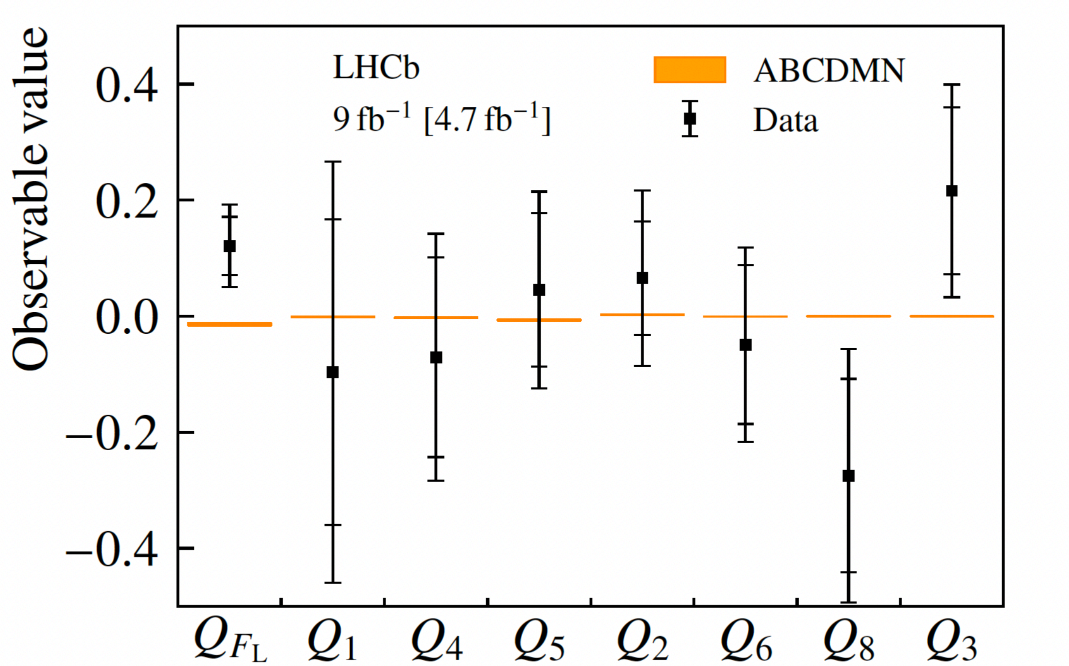
arXiv:2502.10291

Results

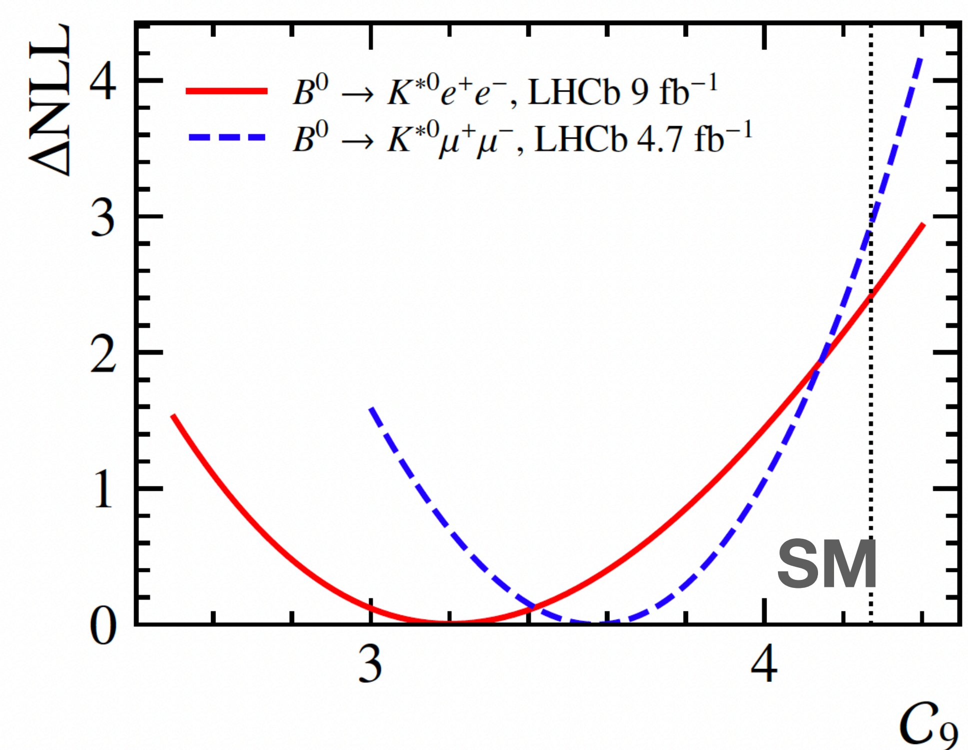


- Results consistent with SM prediction
- Most precise measurement of angular observables in $B^0 \to K^{*0}e^+e^-$ in central q^2

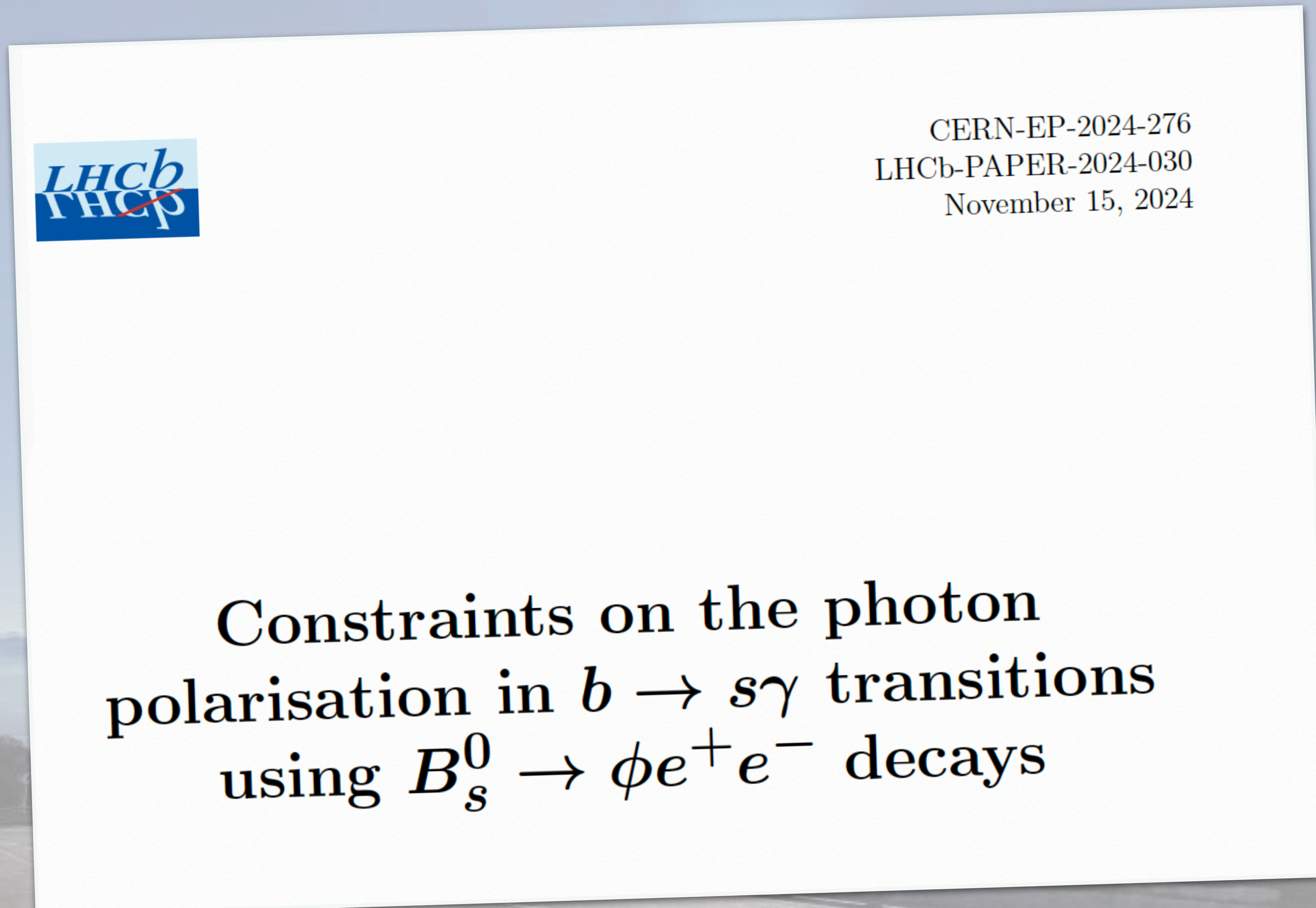
… and consistent with muon modes



$$Q_i = P_i^{(\mu)} - P_i^{(e)}$$



arXiv:2411.10219



CERN-EP-2024-276
LHCb-PAPER-2024-030
November 15, 2024

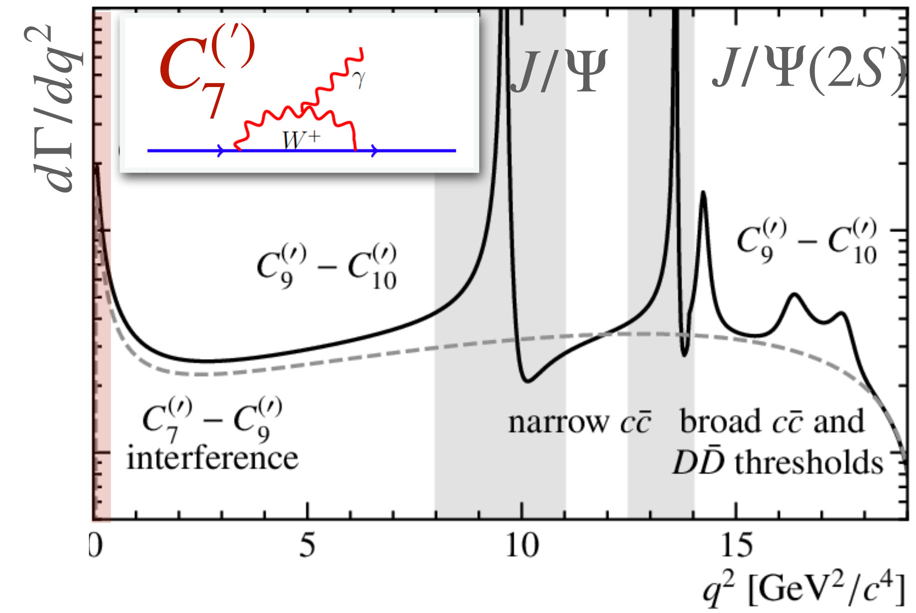
Constraints on the photon polarisation in $b \to s\gamma$ transitions using $B_s^0 \to \phi e^+ e^-$ decays

Angular analysis $B_s^0 \to \phi e^+ e^-$

arXiv:2411.10219

- Measurement at very low q^2 [0.0009, 0.2615] GeV² folding $\tilde{\phi} = \phi \,(\phi > 0)$

$$\tilde{\phi} = \phi + \pi \,(\phi < 0)$$



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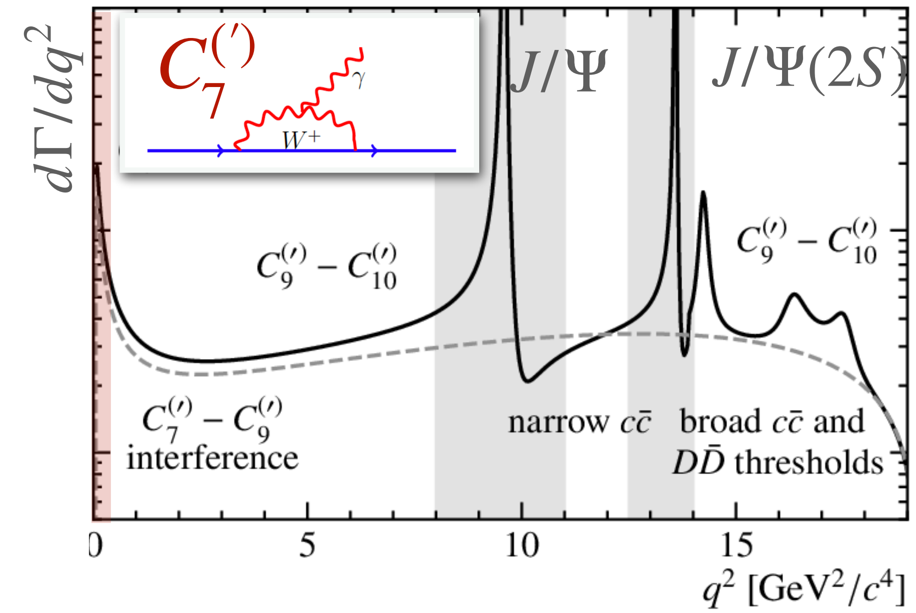
- Measurement at very low q^2 [0.0009, 0.2615] GeV^2 folding $\tilde{\phi} = \phi \, (\phi > 0)$
  $\tilde{\phi} = \phi + \pi \, (\phi < 0)$

$$\frac{1}{\frac{\mathrm{d}(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2}} \frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_L \,\mathrm{d}\cos\theta_K \,\mathrm{d}\tilde{\varphi}} = \frac{9}{32\pi}\Bigg\{\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \left[\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\right]\cos 2\theta_L + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_L\cos 2\tilde{\varphi} + (1-F_L)A_T^{Re\,CP}\sin^2\theta_K\cos\theta_L + \frac{1}{2}(1-F_L)A_T^{Im\,CP}\sin^2\theta_K\sin^2\theta_L\sin 2\tilde{\varphi}\Bigg\}$$



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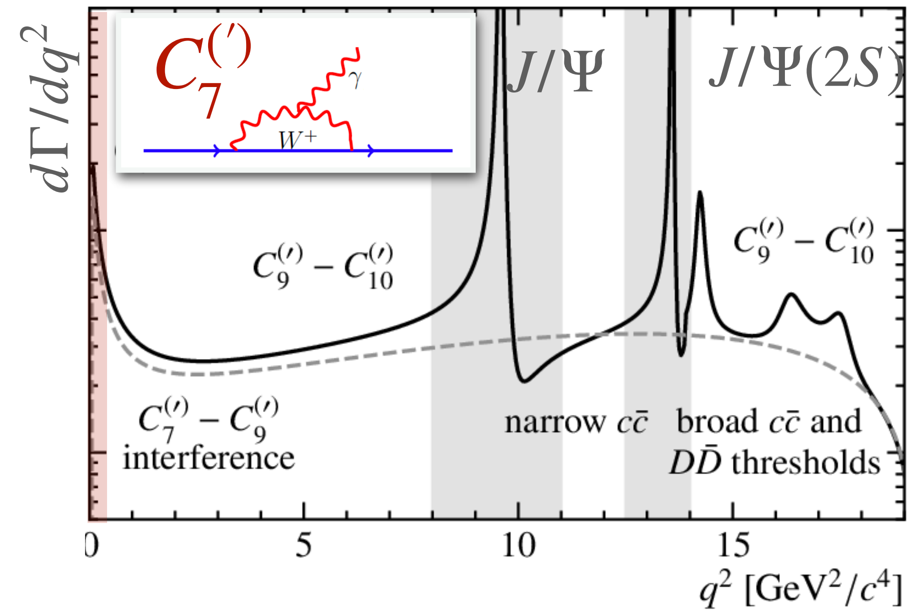
$$\frac{1}{\frac{d(\Gamma+\bar{\Gamma})}{dq^2}} \frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_L \, d\cos\theta_K \, d\tilde{\varphi}} = \frac{9}{32\pi} \left\{ \frac{3}{4}(1-F_L)\sin^2\theta_K + F_L \cos^2\theta_K \right.$$
$$+ \left[\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\right]\cos 2\theta_L$$
$$+\frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K \sin^2\theta_L \cos 2\tilde{\varphi}$$
$$+(1-F_L)A_T^{Re\,CP}\sin^2\theta_K\cos\theta_L$$
$$\left. +\frac{1}{2}(1-F_L)A_T^{Im\,CP}\sin^2\theta_K\sin^2\theta_L\sin 2\tilde{\varphi} \right\}$$



- Limit $q^2 \to 0$

$$A_T^{(2)}(q^2 \to 0) \propto \frac{\mathrm{Re}(C_7)\mathrm{Re}(C_7') + \mathrm{Im}(C_7)\mathrm{Im}(C_7')}{|C_7|^2 + |C_7'|^2} + \Delta_1^2$$

$$A_T^{ImCP}(q^2 \to 0) \propto \frac{\mathrm{Re}(C_7)\mathrm{Im}(C_7') + \mathrm{Im}(C_7)\mathrm{Re}(C_7')}{|C_7|^2 + |C_7'|^2} + \Delta_2^2$$

Δ_i due to $\Delta\Gamma_s$

Sensitive to left (C_7) and right handed (C_7') EM operators
→ Photon Polarisation!

SM $C_7' \sim 0$ (in $B_s^0 \to \phi\gamma$)

Angular analysis $B_s^0 \to \phi e^+ e^-$

arXiv:2411.10219

Results

- Analysis using data (9/fb) recorded during Run I + Run II
- consistent with the SM predictions

Stat. Sys.

$$
\begin{aligned}
A_{\mathrm{T}}^{(2)} &= -0.045 \pm 0.235 \pm 0.014\,, \\
A_{\mathrm{T}}^{\mathcal{I}mCP} &= 0.002 \pm 0.247 \pm 0.016\,, \\
A_{\mathrm{T}}^{\mathcal{R}eCP} &= 0.116 \pm 0.155 \pm 0.006\,, \\
F_{\mathrm{L}} &= (0.4 \pm 5.6 \pm 1.2)\%\,,
\end{aligned}
$$

Angular analysis $B_s^0 \to \phi e^+ e^-$

arXiv:2411.10219

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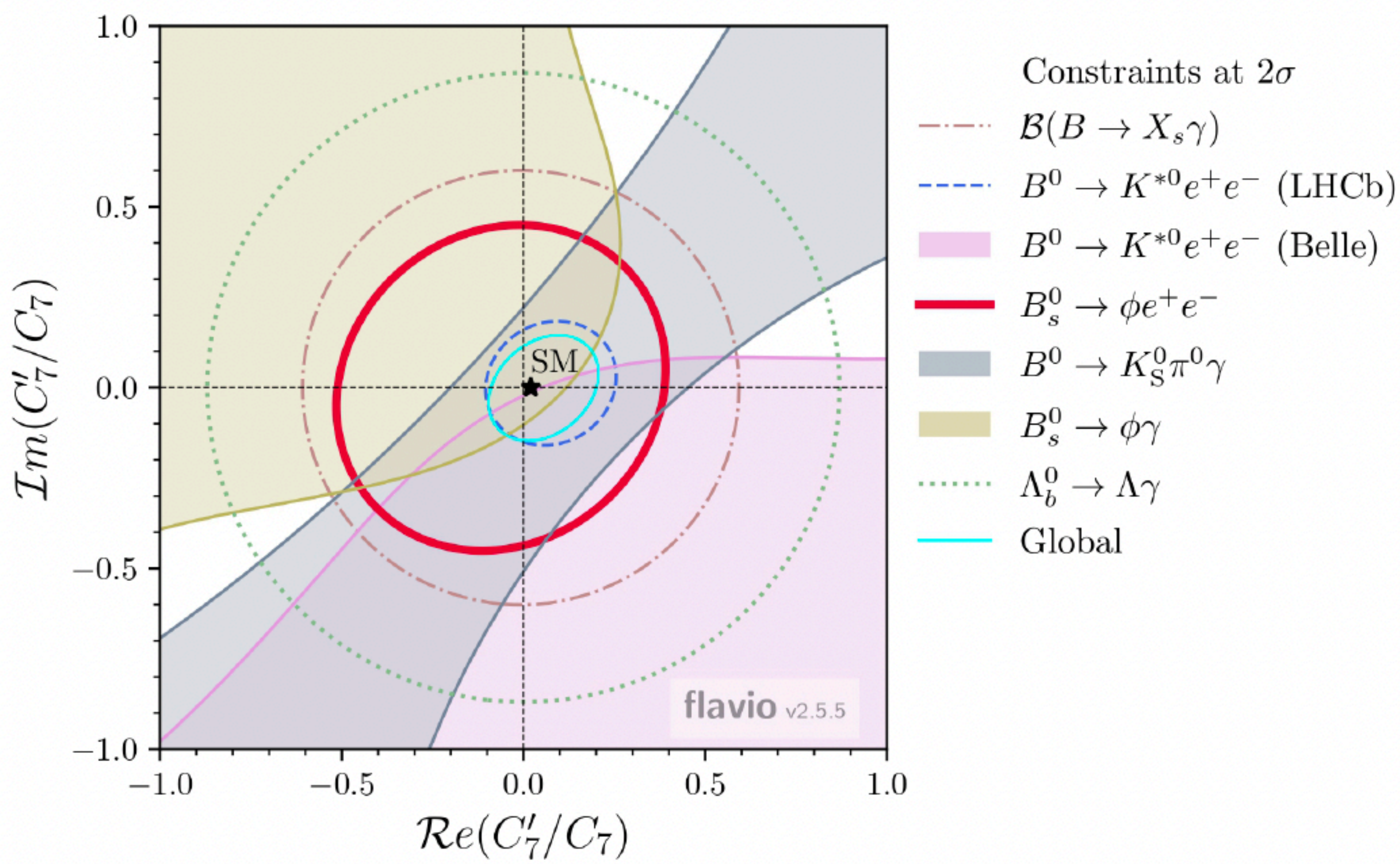
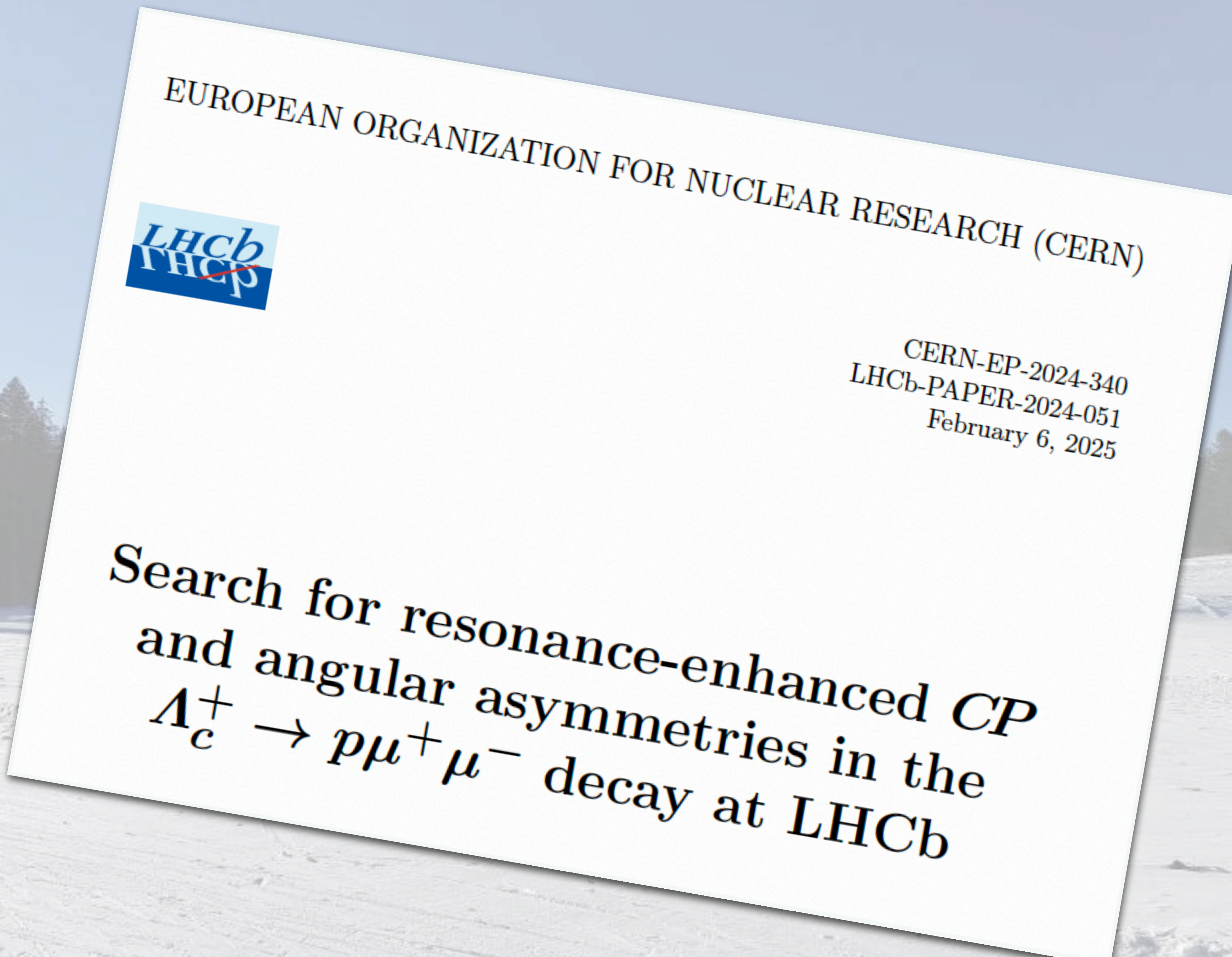


Real and imaginary part of $B_s^0 \to \phi\gamma$ photon polarisation consistent with SM

arXiv:2502.04013



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2024-340
LHCb-PAPER-2024-051
February 6, 2025

Search for resonance-enhanced CP and angular asymmetries in the $\Lambda_c^+ \to p\mu^+\mu^-$ decay at LHCb

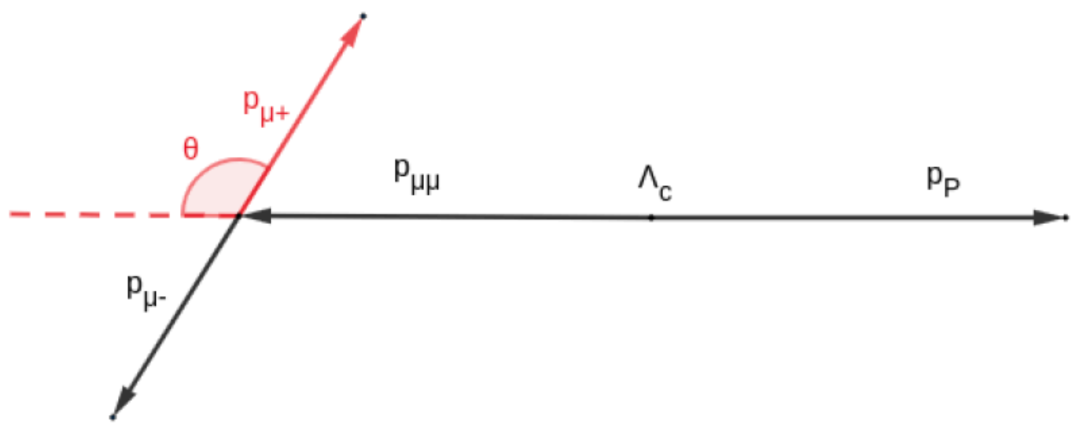
Asymmetries in $\Lambda_c^+ \to p\mu^+\mu^-$ arXiv:2502.04013

- First study of angular and CP asymmetries in rare baryonic charm decay $\Lambda_c^+ \to p\mu^+\mu^-$

M. Colonna, Talk at DISCRETE (2024)

$$A_{CP} \equiv \frac{\Gamma(\Lambda_c^+ \to p\mu^+\mu^-) - \Gamma(\Lambda_c^- \to \bar{p}\mu^+\mu^-)}{\Gamma(\Lambda_c^+ \to p\mu^+\mu^-) + \Gamma(\Lambda_c^- \to \bar{p}\mu^+\mu^-)}$$

$$A_{FB} \equiv \frac{\Gamma(\cos\theta > 0) - \Gamma(\cos\theta < 0)}{\Gamma(\cos\theta > 0) + \Gamma(\cos\theta < 0)}$$



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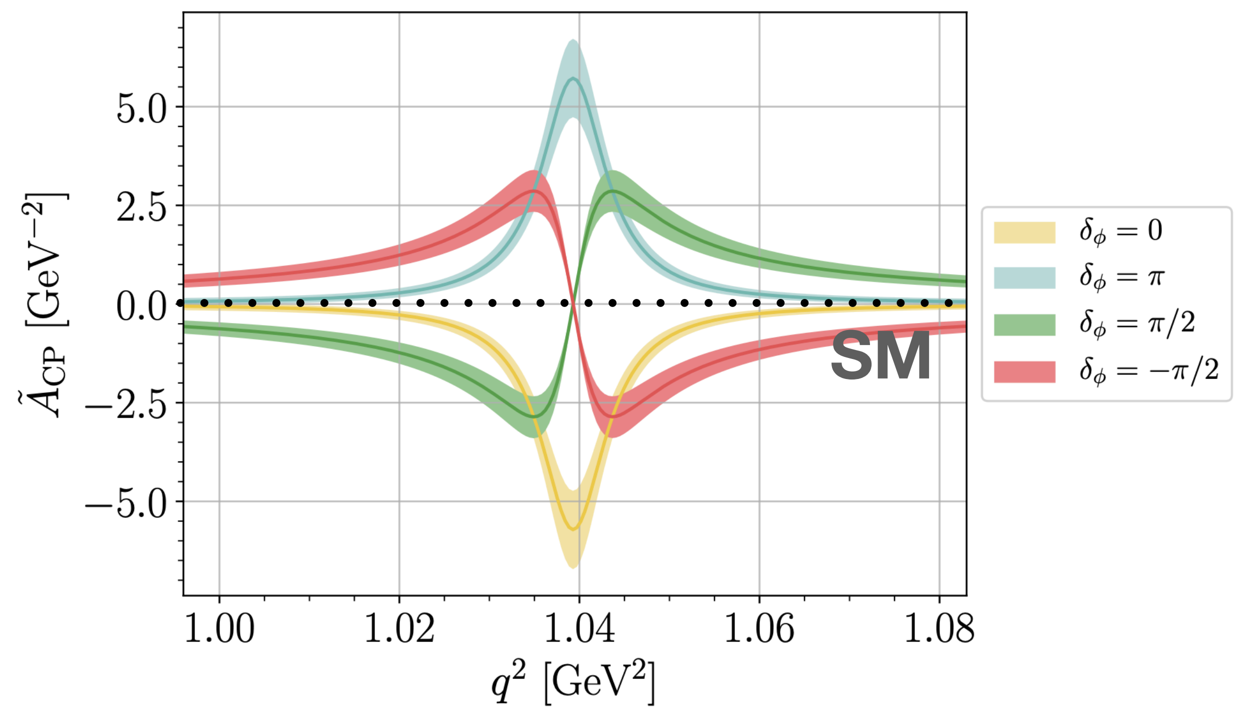
JHEP 09 (2021) 208



- Decays dominated by resonance contributions $\Lambda_c^+ \to p\phi(\to \mu^+\mu^-)$

Hunt for BSM - SM interference in null tests!

Asymmetries in $\Lambda_c^+ \to p\mu^+\mu^-$ arXiv:2502.04013

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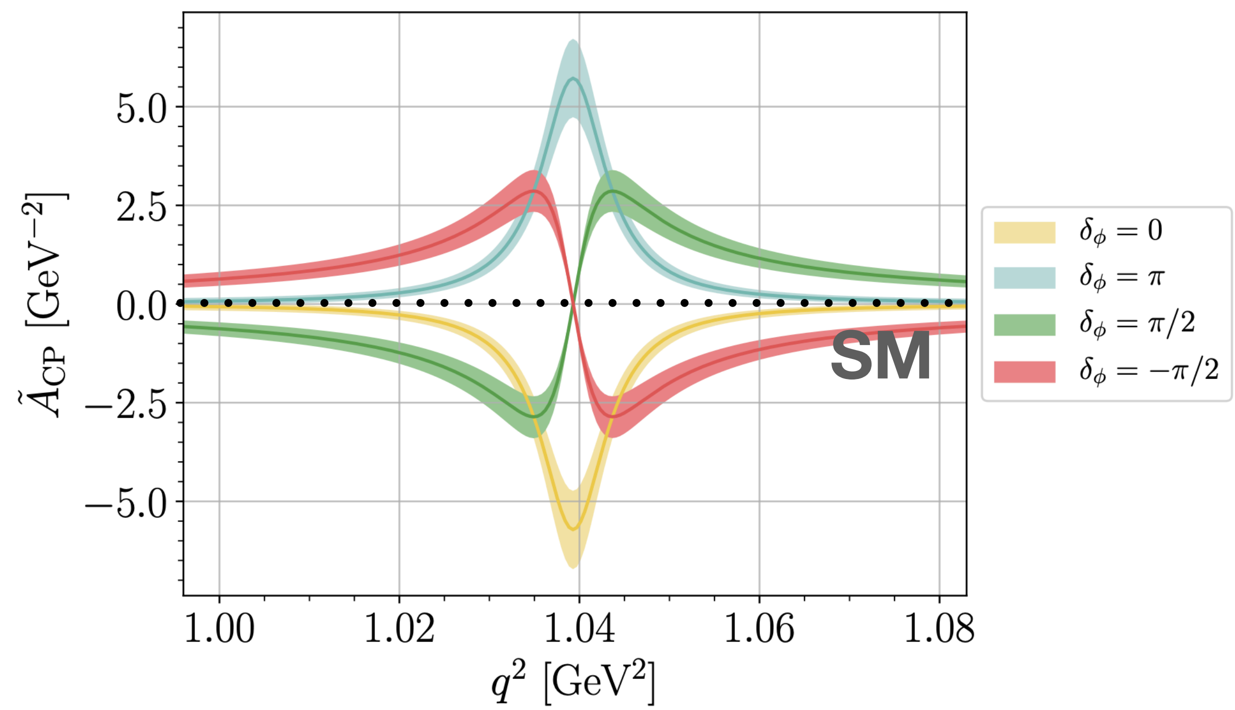
- Decays dominated by resonance contributions $\Lambda_c^+ \to p\phi(\to \mu^+\mu^-)$

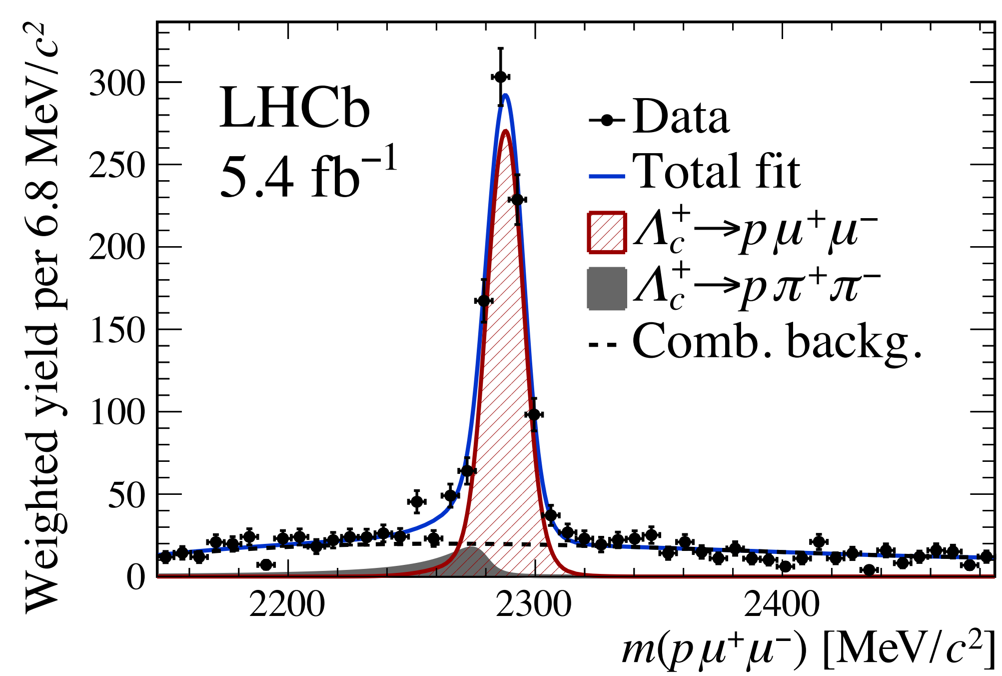
  Hunt for BSM - SM interference in null tests!

- Analysis using data (5.4/fb) recorded during Run II

  ~800 signal candidates in $m(\mu^+\mu^-)$ around ϕ resonance

JHEP 09 (2021) 208





Asymmetries in $\Lambda_c^+ \to p\mu^+\mu^-$ arXiv:2502.04013

- Measure A_{FB} separate for Λ_c^+ and $\bar{\Lambda}_c^-$ and define:

$$\Sigma A_{\mathrm{FB}}^{CP} \equiv 1/2 \cdot \left[A_{\mathrm{FB}}^{\Lambda_c^+} + A_{\mathrm{FB}}^{\bar{\Lambda}_c^-} \right]$$

$$\Delta A_{\mathrm{FB}}^{CP} \equiv 1/2 \cdot \left[A_{\mathrm{FB}}^{\Lambda_c^+} - A_{\mathrm{FB}}^{\bar{\Lambda}_c^-} \right]$$

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Results

dimuon-mass integrated

Stat. Sys.

$$A_{CP} = (-1.1 \pm 4.0 \pm 0.5)\%$$
$$\Sigma A_{\mathrm{FB}} = (\ \ 3.9 \pm 4.0 \pm 0.6)\%$$
$$\Delta A_{\mathrm{FB}} = (\ \ 3.1 \pm 4.0 \pm 0.4)\%$$

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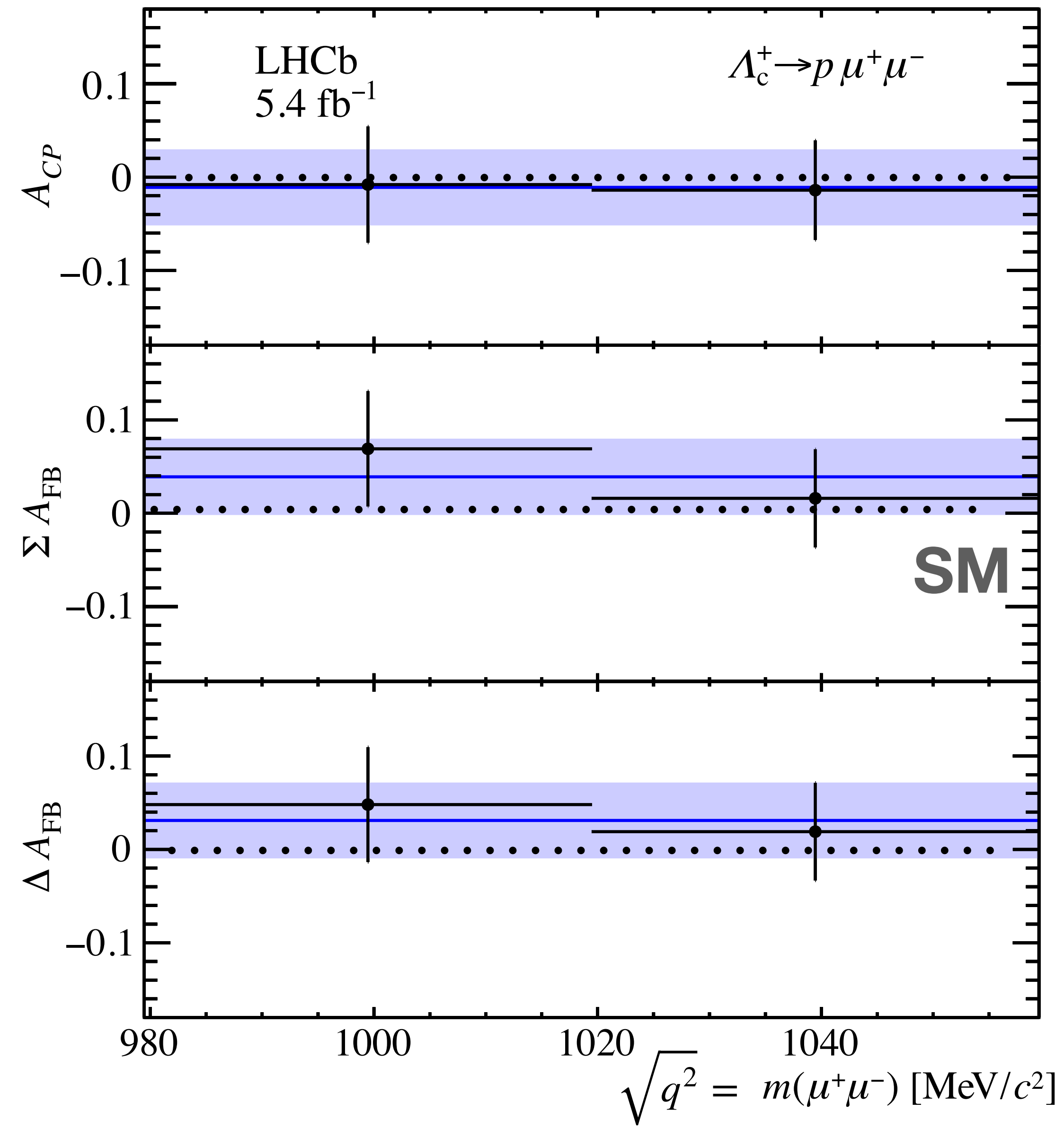
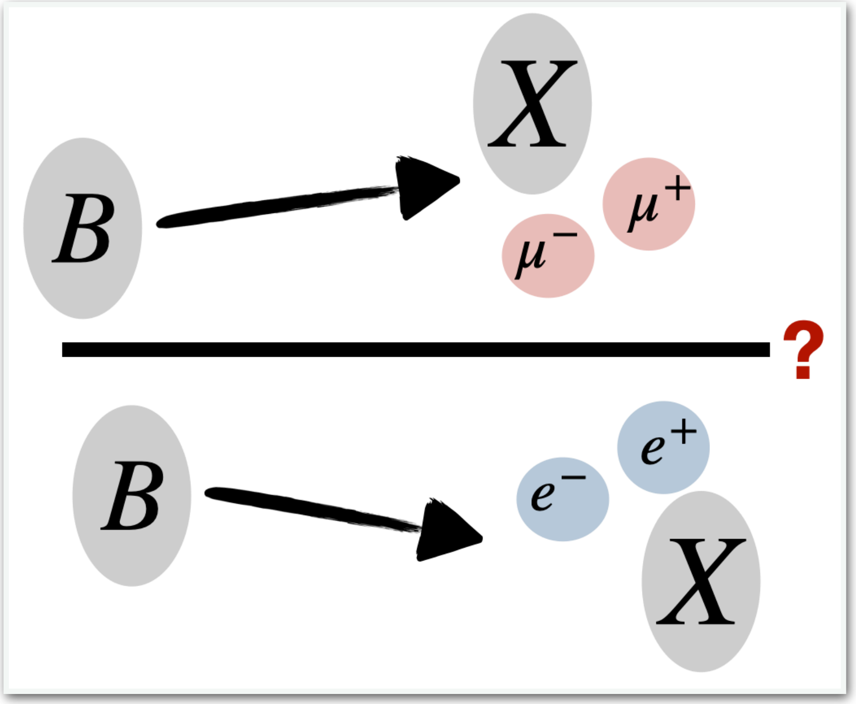


Compatible with SM prediction and conservation of P and CP symmetry!

Tests of LU



Status Quo

- Measurement of ratio of branching fractions

$$R_X = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathscr{B}(B \to X\mu^+\mu^-)}{dq^2} dq^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathscr{B}(B \to Xe^+e^-)}{d^2} dq^2}$$

- Ratio largely unaffected by hadronic uncertainties, R_{SM} ~1 clear null test

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- Measurement of ratio of branching fractions

Phys. Rev. D 108 (2023) 032002

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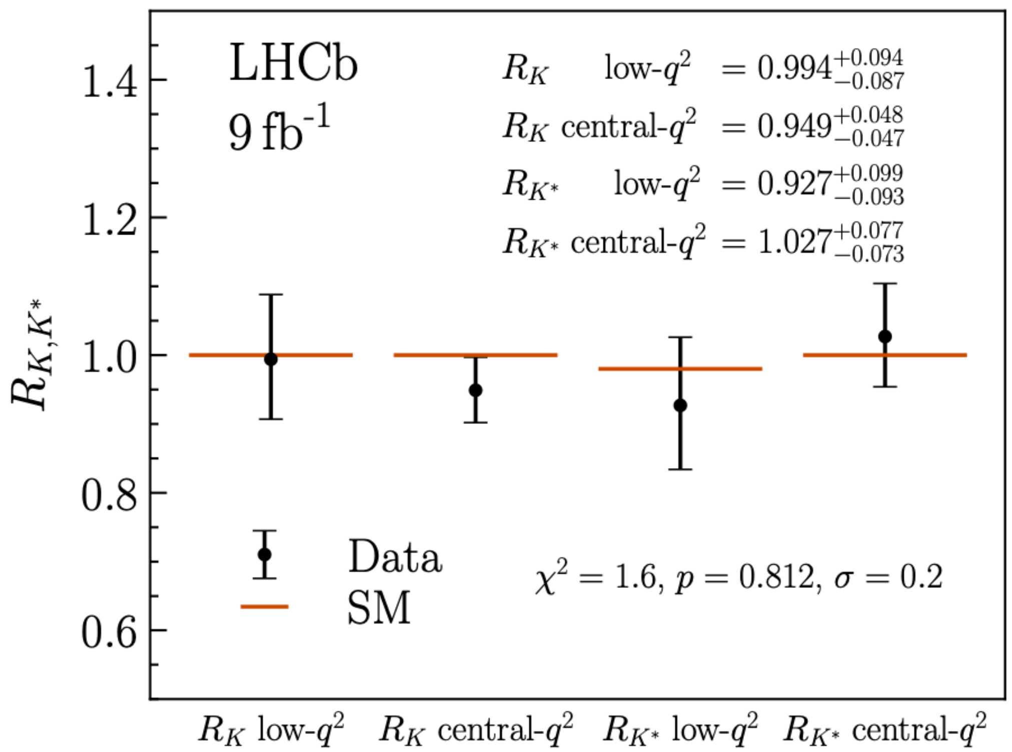

- Ratio largely unaffected by hadronic uncertainties, R_{SM} ~1 clear null test

- Previous studies in $B^{0,+} \to K^{*0,+}\ell^+\ell^-$ and $\Lambda_b \to pK^-\ell^+\ell^-, B^0_s \to \phi\ell^+\ell^-$ in agreement with SM prediction

Phys. Rev. D 108 (2023) 032002 Phys. Rev. Lett. 131 (2023) 051803 arXiv:2410.13748

Phys. Rev. Lett. 128, 191802 JHEP 05 (2020) 040

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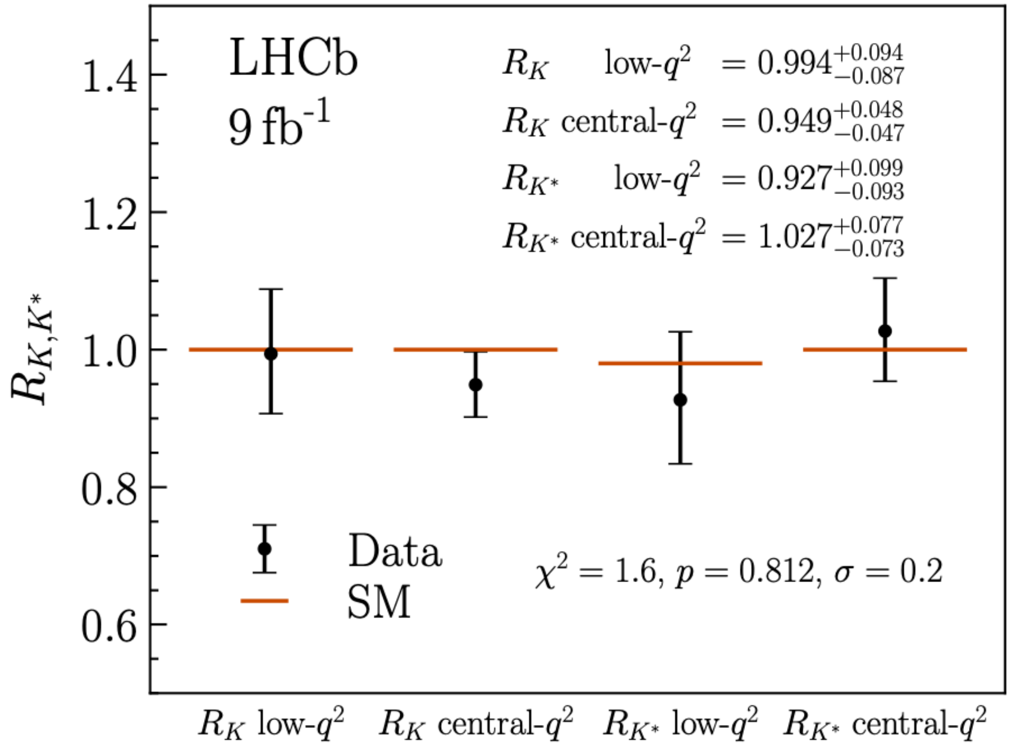
Phys. Rev. D 108 (2023) 032002

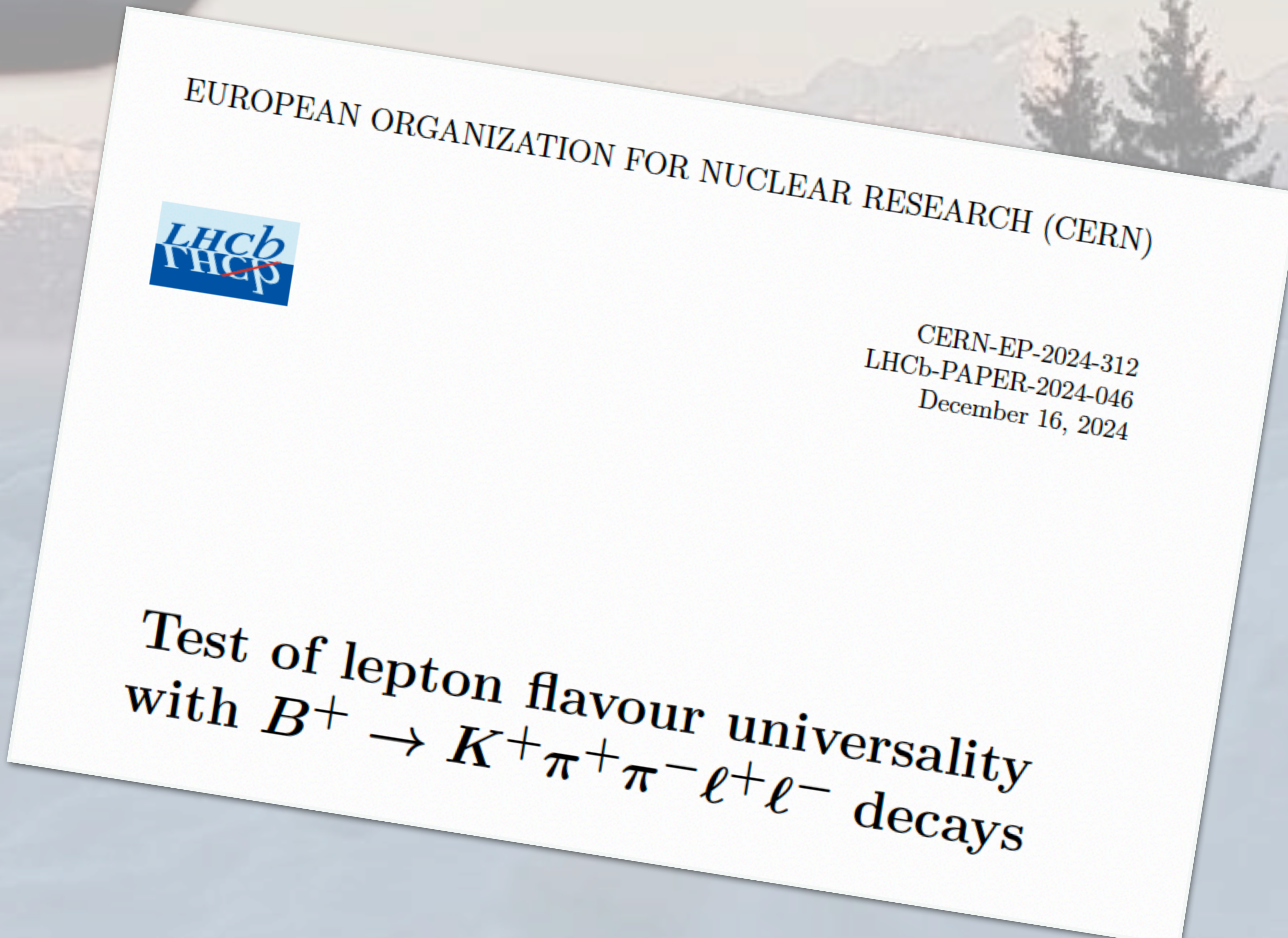


Phys. Rev. D 108 (2023) 032002 Phys. Rev. Lett. 131 (2023) 051803 arXiv:2410.13748

Phys. Rev. Lett. 128, 191802 JHEP 05 (2020) 040

Open questions: Other decay modes? High q^2 ?

arXiv:2412.11645



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2024-312
LHCb-PAPER-2024-046
December 16, 2024

Test of lepton flavour universality with $B^+ \to K^+\pi^+\pi^-\ell^+\ell^-$ decays

LU in $B^+ \to K^+\pi^+\pi^-\ell^+\ell^-$

arXiv:2412.11645

- Experimental measure a double ratio in central $q^2 = [1.1, 7]$ GeV

$$R_X = \frac{N_{B\to X\mu^+\mu^-}}{} \cdot \frac{}{N_{B\to Xe^+e^-}} \cdot \frac{}{\epsilon_{B\to X\mu^+\mu^-}} \cdot \frac{\epsilon_{B\to Xe^+e^-}}{}$$

Yields from maximum-likelihood fits to data

Efficiencies from fits from simulations and corrected using data control samples

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arXiv:2412.11645

- Experimental measure a double ratio in central $q^2 = [1.1,7]$ GeV

$$R_X = \frac{N_{B\to X\mu^+\mu^-}}{N_{B\to XJ/\psi(\to\mu^+\mu^-)}} \cdot \frac{N_{B\to XJ/\psi(\to e^+e^-)}}{N_{B\to Xe^+e^-}} \cdot \frac{\epsilon_{B\to XJ/\psi(\to\mu^+\mu^-)}}{\epsilon_{B\to X\mu^+\mu^-}} \cdot \frac{\epsilon_{B\to Xe^+e^-}}{\epsilon_{B\to XJ/\psi(\to e^+e^-)}}$$

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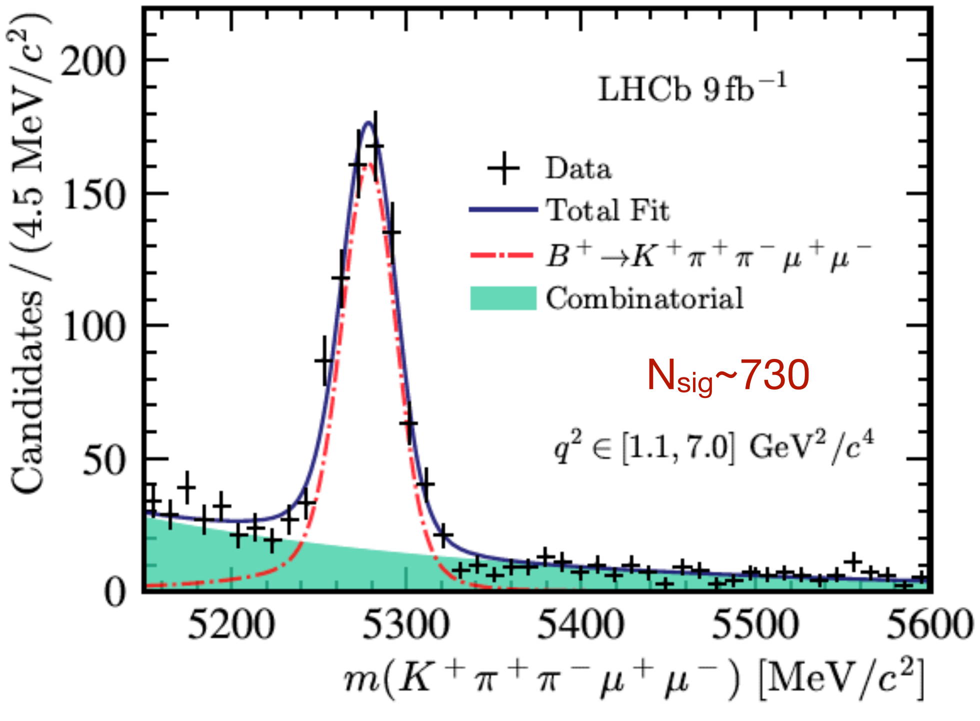

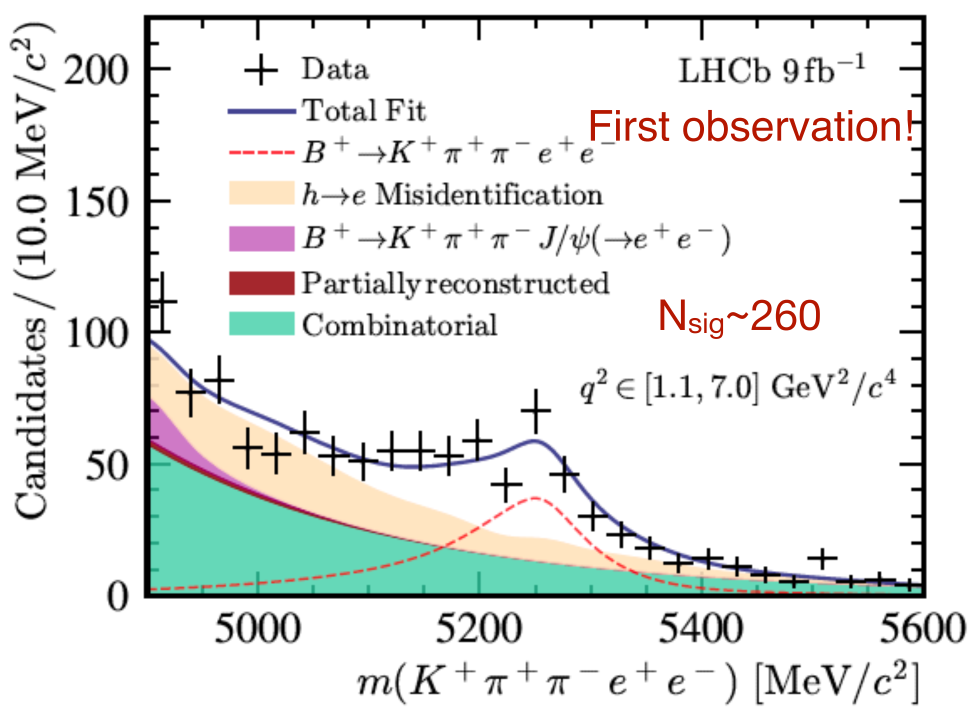

- Analysis using full Run I and Run II data set (9/fb)
  - Measurement integrated over complex hedonic system ($[1.1, 2.4]$GeV)
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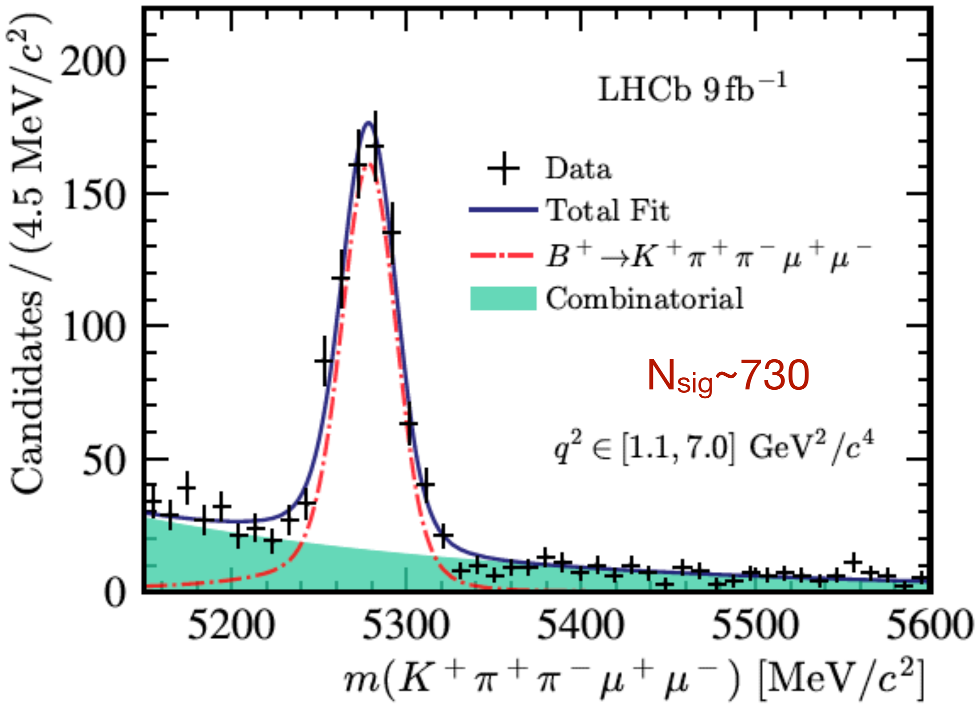

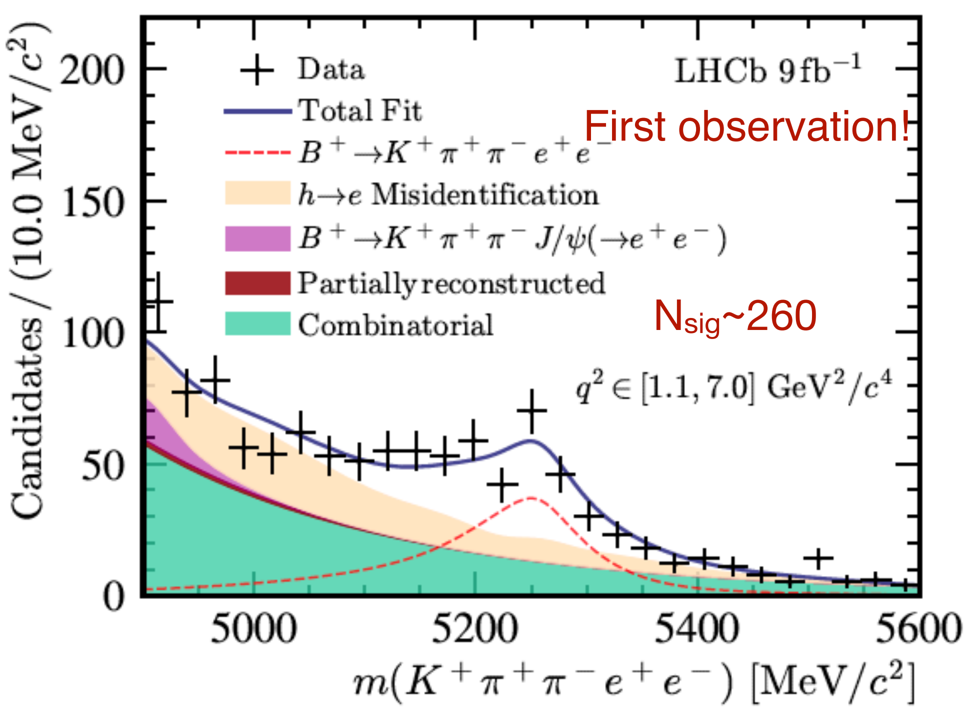

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  - Cross checks using J/Ψ and J/Ψ(2S) (known to conserve LU)

$$r_{J/\psi} = 1.033 \pm 0.017$$

$$R_{\psi(2S)} = 1.040 \pm 0.030$$

LU in $B^+ \to K^+\pi^+\pi^-\ell^+\ell^-$

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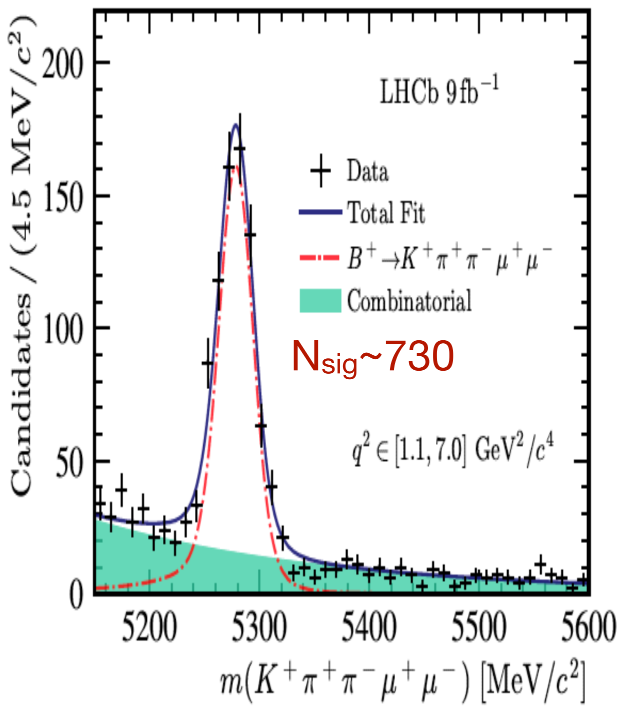

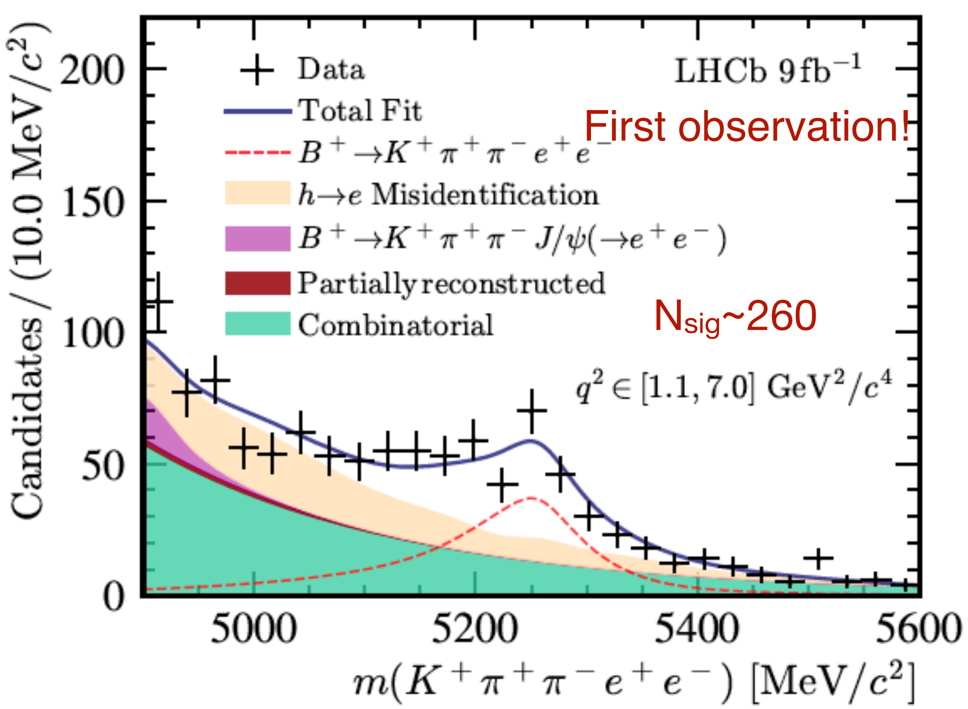

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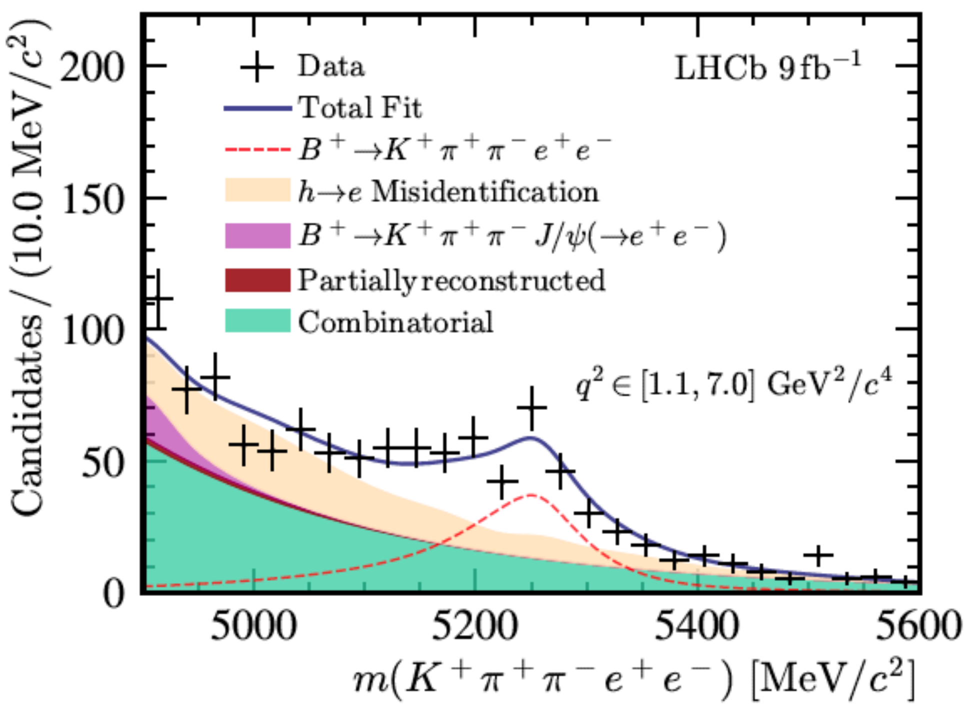
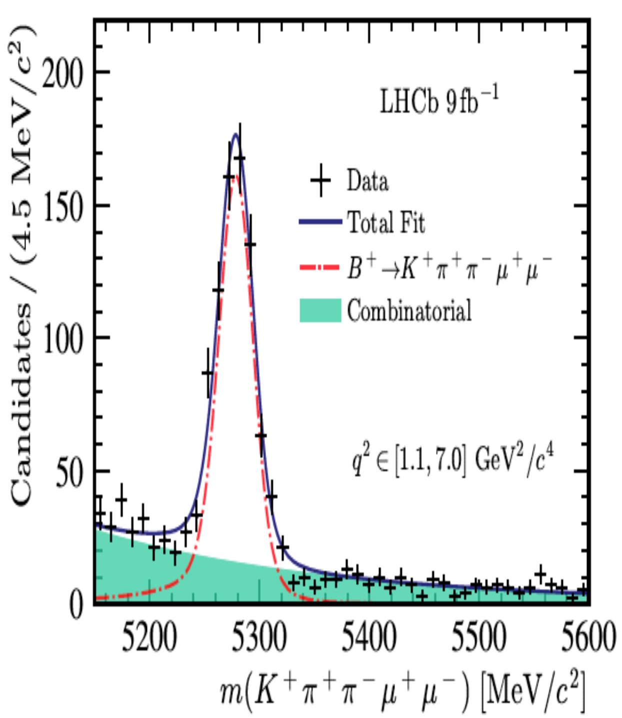
arXiv:2412.11645





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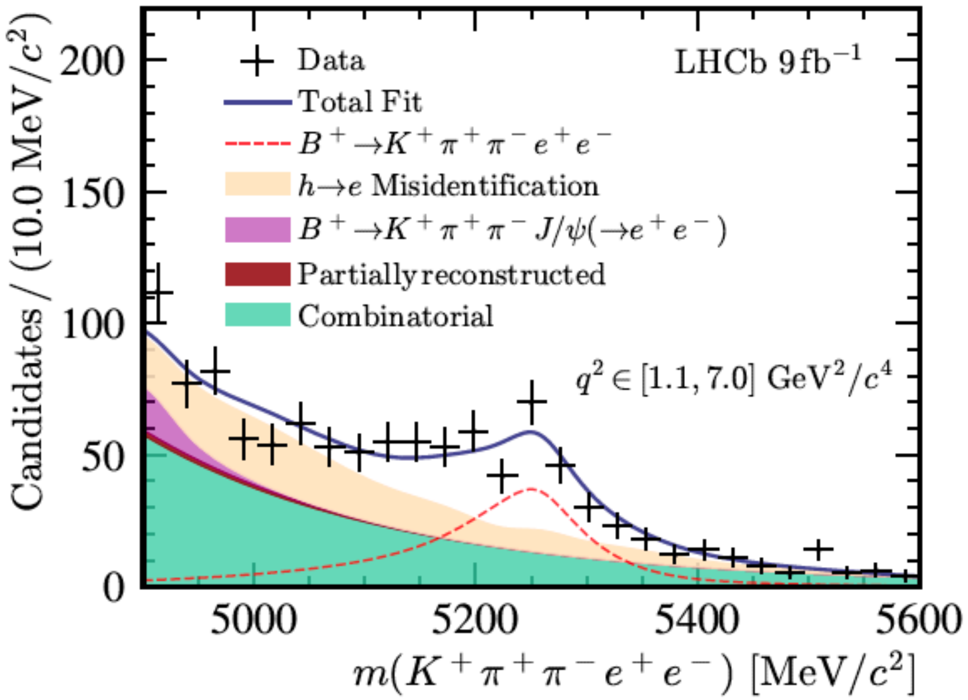
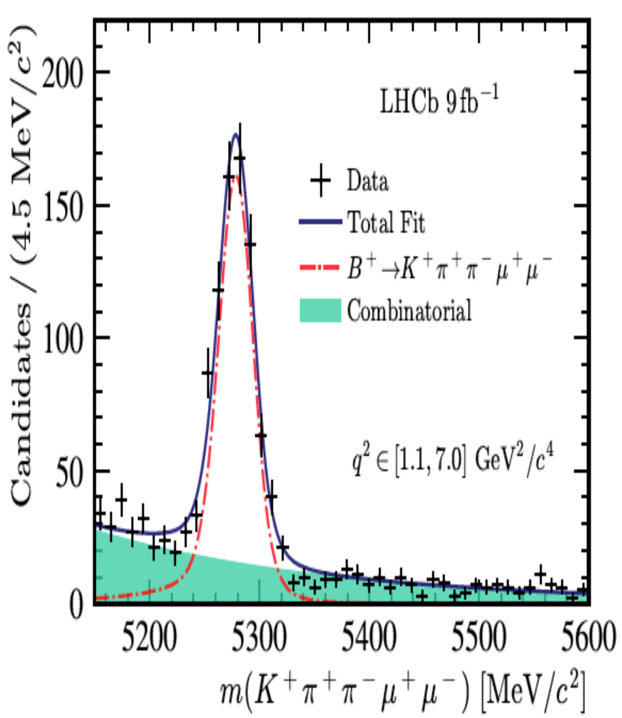
LU in $B^+ \to K^+\pi^+\pi^-\ell^+\ell^-$

arXiv:2412.11645





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$$r_{J/\psi} = 1.033 \pm 0.017$$

$$R_{\psi(2S)} = 1.040 \pm 0.030$$

- Measure $R^{-1}_{K\pi\pi}$ instead of $R_{K\pi\pi}$

$$R^{-1}_{K\pi\pi} = 1.31^{+0.18}_{-0.17}\,(\text{stat})\,^{+0.12}_{-0.09}\,(\text{syst})$$

In agreement with the SM predictions

LHCb-PAPER-2024-056
in preparation

CERN-EP-20XX-ZZZ
LHCb-PAPER-2024-056
????????? 2025

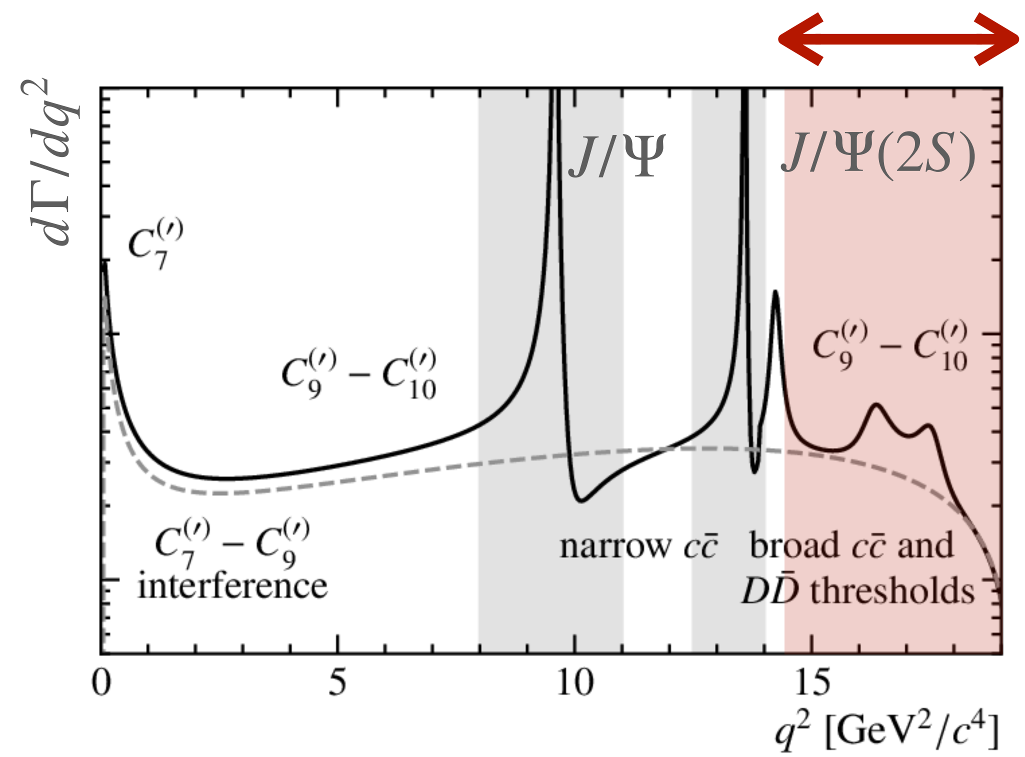
Brand New!

Measurement of the branching fraction ratio R_K at large dilepton invariant mass

LU in $B^+ \to K^+\ell^+\ell^-$ high q^2

LHCb-PAPER-2024-056
in preparation

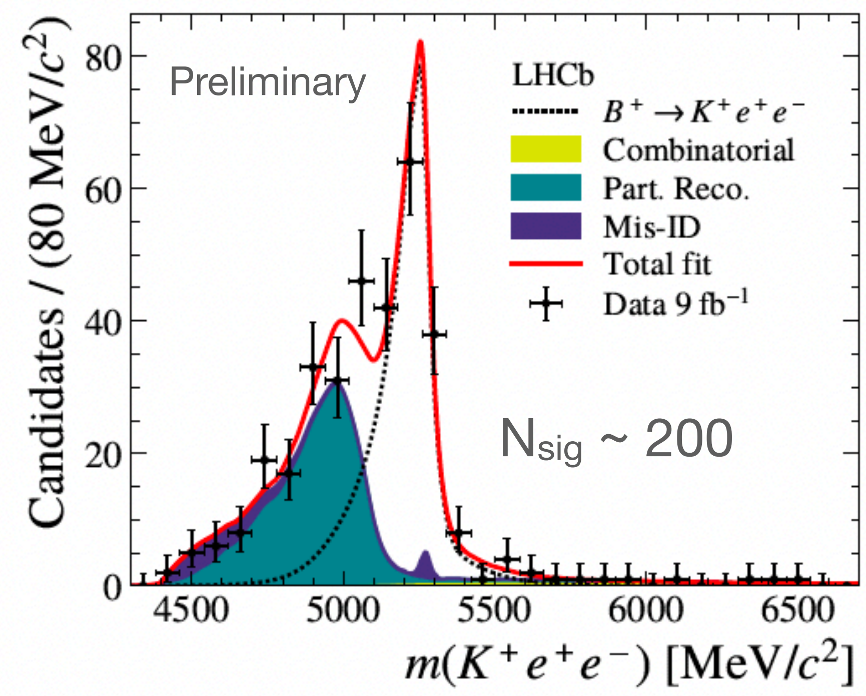
- First lepton flavour universality test in high q^2 region >14.3 GeV² of $B^+ \to K^+\ell^+\ell^-$ at LHCb



LU in $B^+ \to K^+\ell^+\ell^-$ high q^2

LHCb-PAPER-2024-056
in preparation

- First lepton flavour universality test in high q^2 region >14.3 GeV^2 of $B^+ \to K^+\ell^+\ell^-$ at LHCb
  - Important additional information, as affected differently by acceptance and background
  - Strategy aligned with previous LU tests
  - Analysis of Run I + Run II (9/fb) with ~200 $B^+ \to K^+\ell^+\ell^-$ signals



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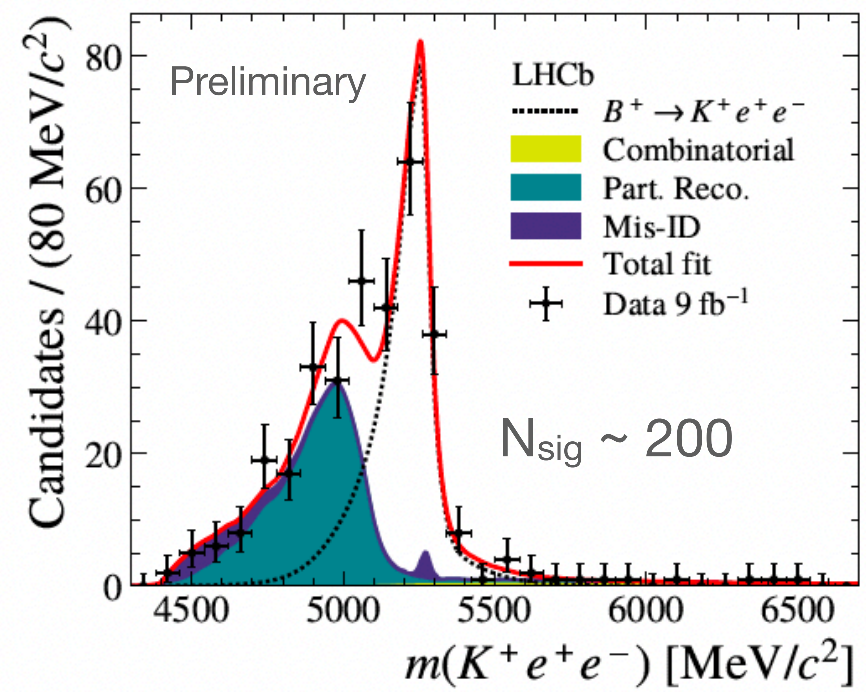
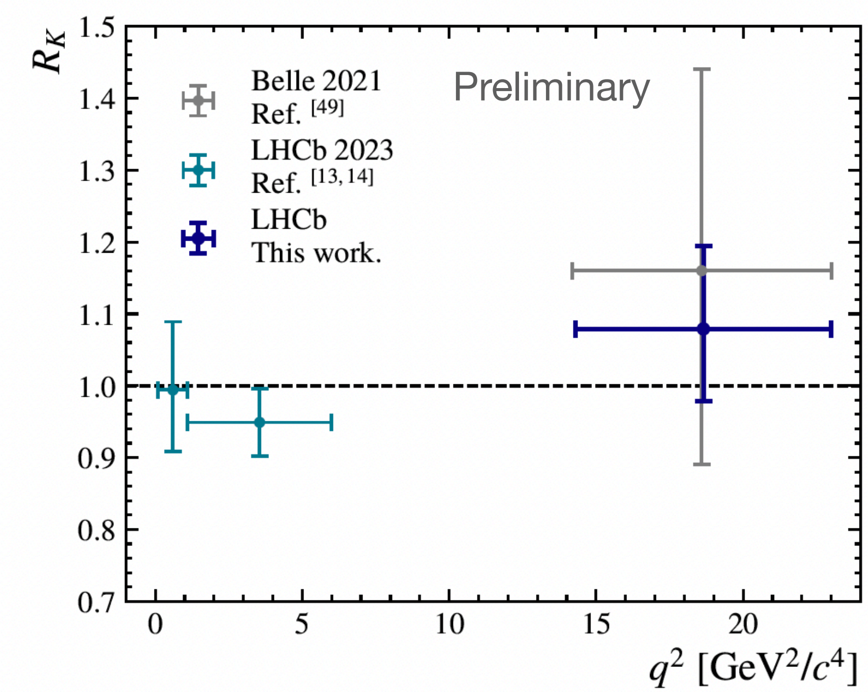
$$R_K(q^2 > 14.3\ \text{GeV}^2/c^4) = 1.079^{+0.106}_{-0.092}\,^{+0.044}_{-0.040}$$

Stat. Sys.





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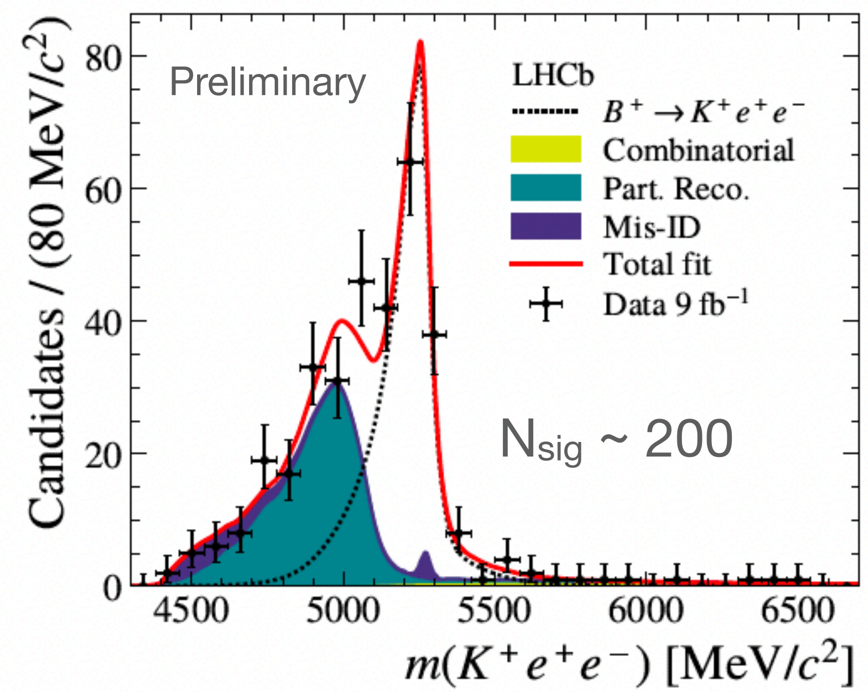
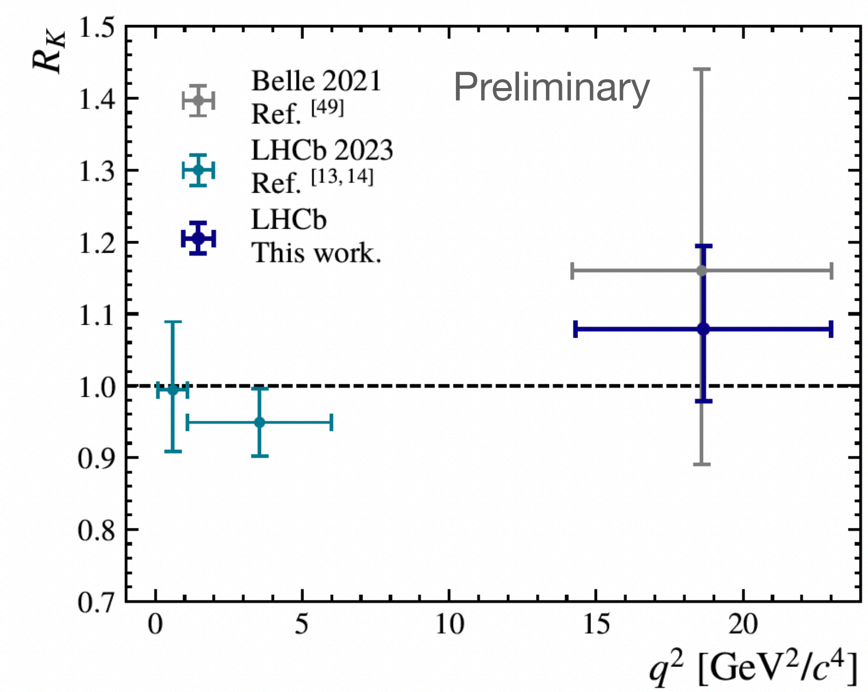




Most precise LU test in b→s transition at high q^2 and compatible with SM

arXiv:2412.09414

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2024-307
LHCb-PAPER-2024-047
December 17, 2024

Search for D^0 meson decays to $\pi^+\pi^-e^+e^-$ and $K^+K^-e^+e^-$ final states

Search for $D^0 \to h^+h^-e^+e^-$

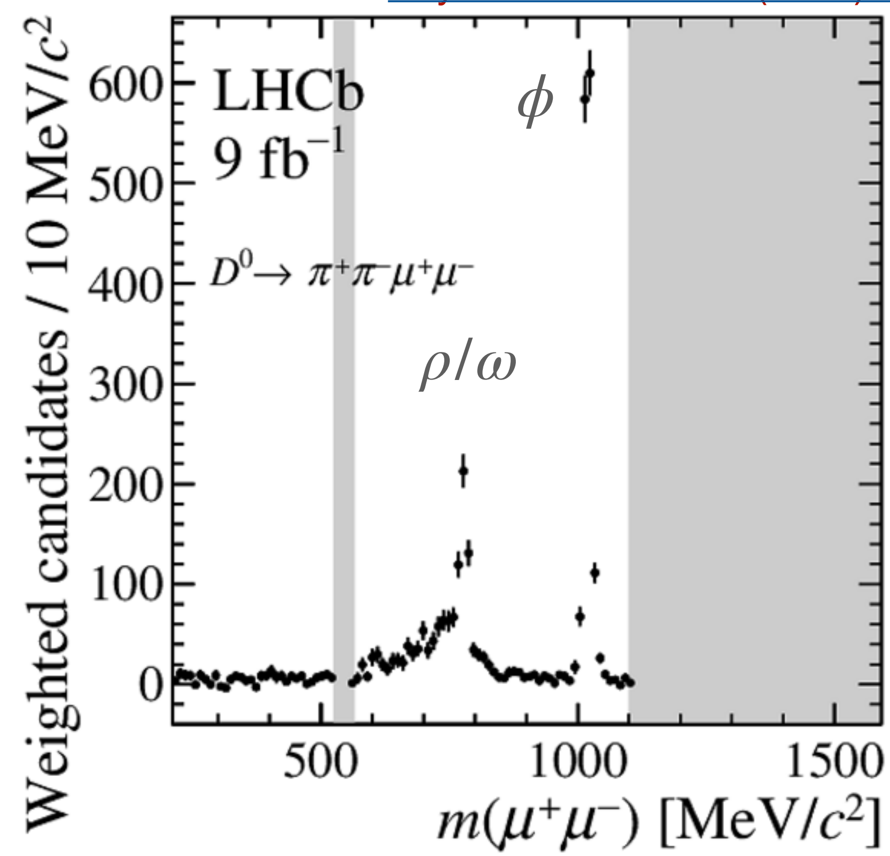
arXiv:2412.09414

- $D^0 \to \pi^+\pi^-\mu^+\mu^-$ ($D^0 \to K^+K^-\mu^+\mu^-$) decays observed by LHCb with $\mathscr{B} \sim 10^{-6}\,(10^{-7})$

  Phys. Rev. Lett. 119 (2017) 181805

- Dominated by intermediate resonances, still very suppressed and sensitive to BSM

Phys. Rev. Lett. 128 (2022) 221801



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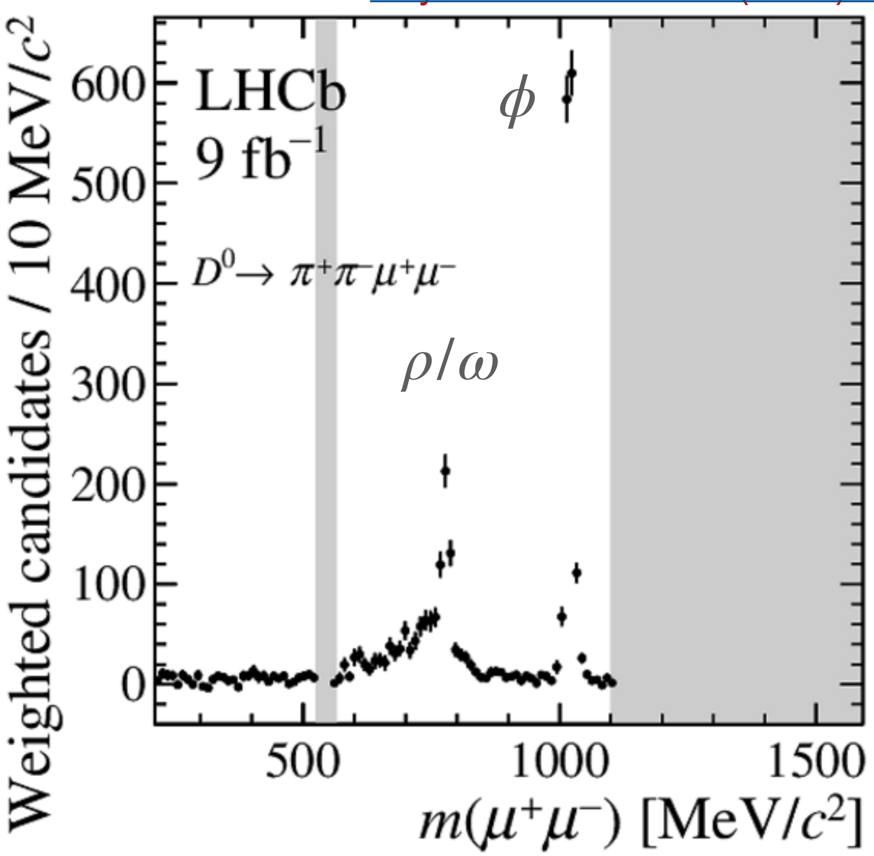

- Now: First search for dielectron modes

  - Measurement based on full Run II data (6/fb)

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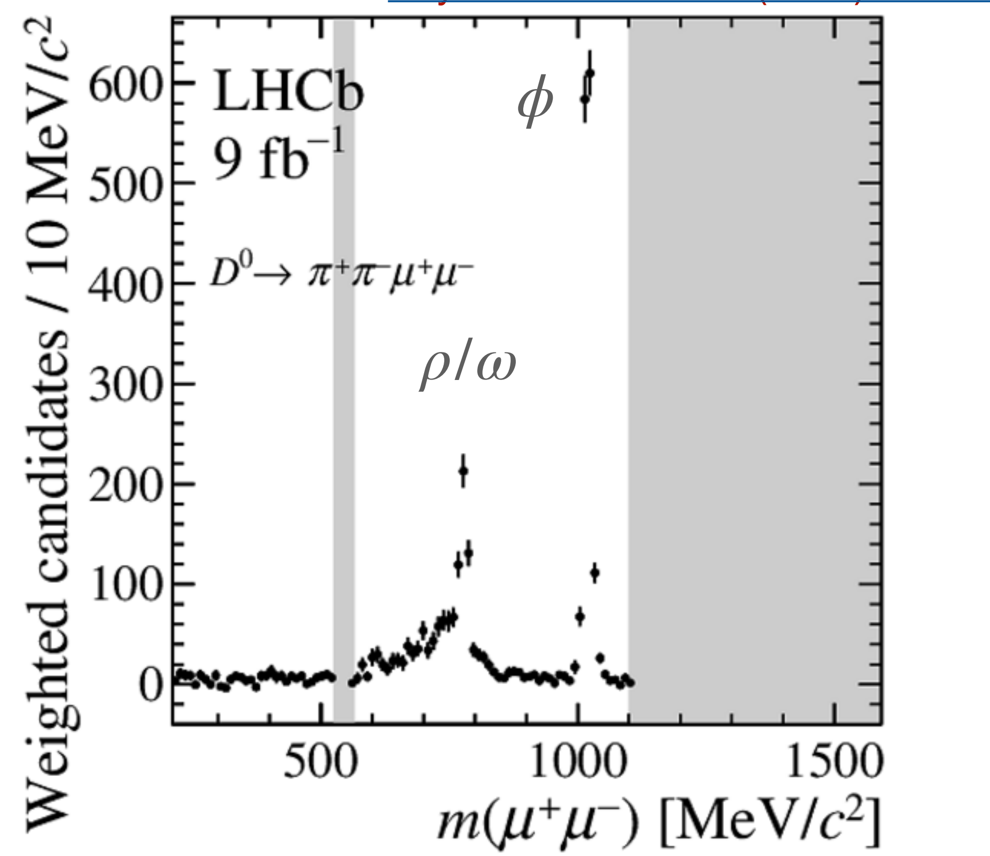


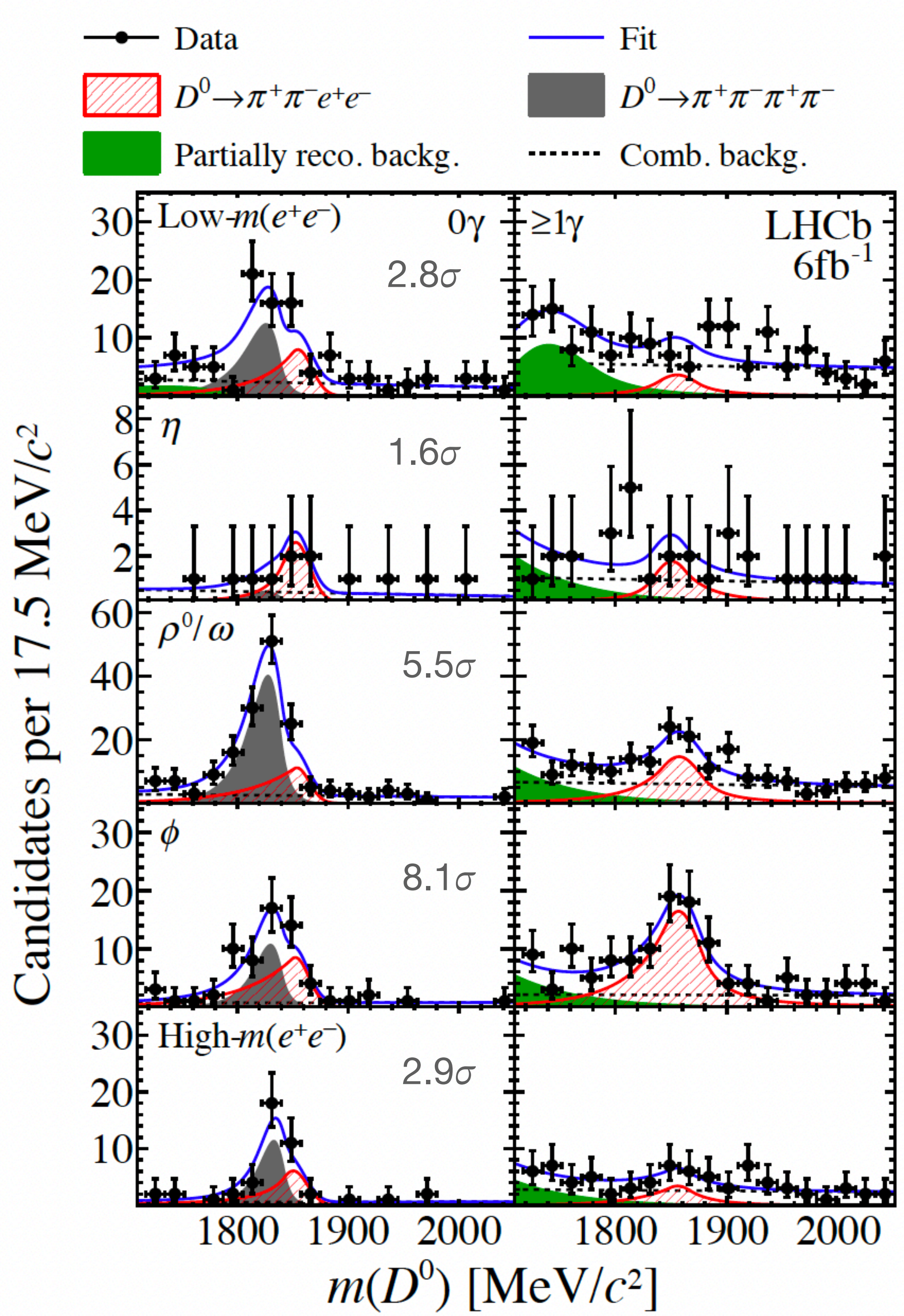
Lepton universality in rare charm decays mostly unconstrained

Search for $D^0 \to h^+h^-e^+e^-$

arXiv:2412.09414

Results

- First observation of $D^0 \to \pi^+\pi^-e^+e^-$



Search for $D^0 \to h^+h^-e^+e^-$

arXiv:2412.09414

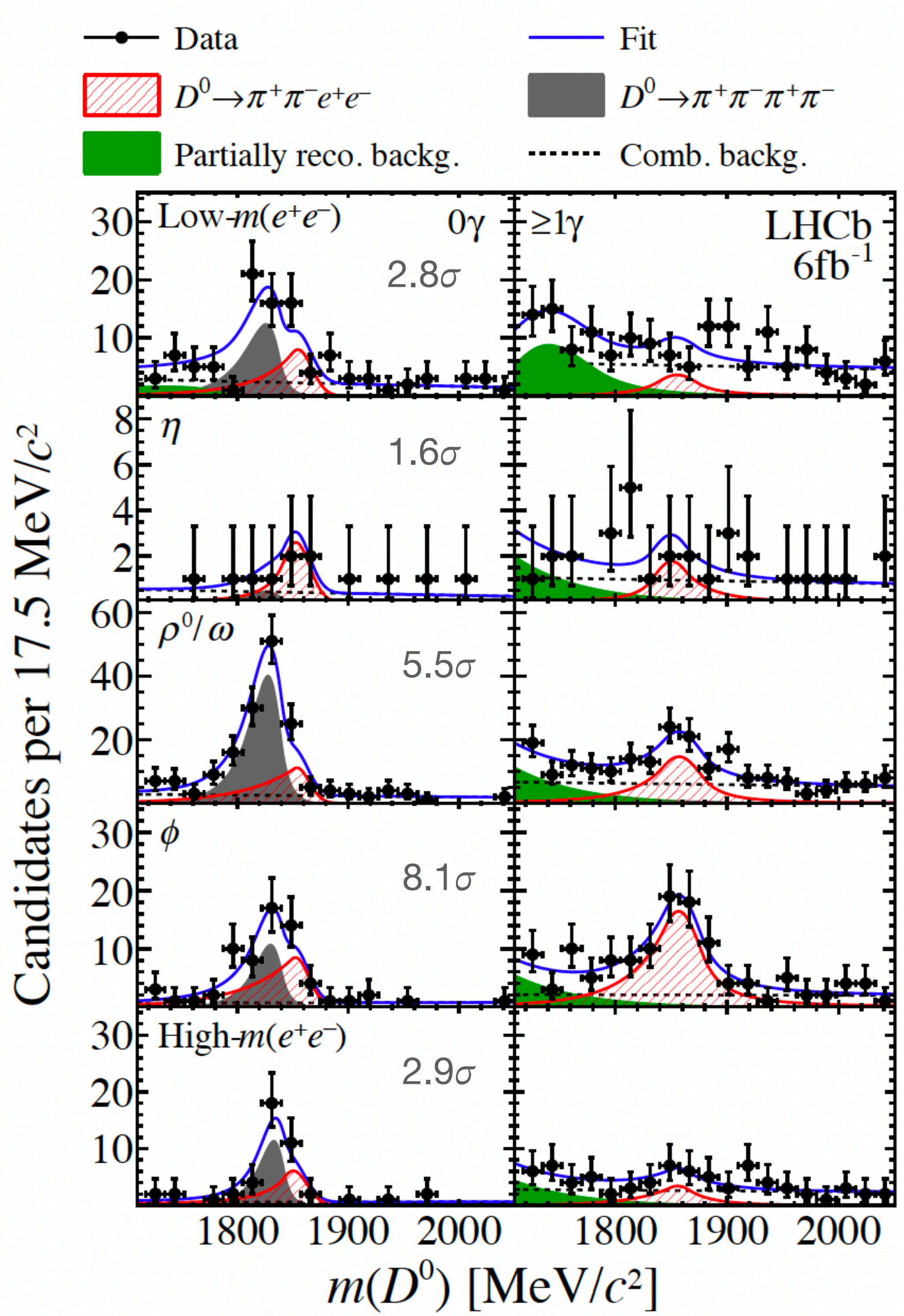
Results

- **First observation** of $D^0 \to \pi^+\pi^-e^+e^-$

$m(e^+e^-)$ region	[MeV/c^2]	$\mathcal{B}$ [10^{-7}]
	$D^0 \to \pi^+\pi^-e^+e^-$	
Low mass	$2m_\mu$–525	$< 4.8\,(5.4)$
η	525–565	$< 2.3\,(2.7)$
ρ^0/ω	565–950	$4.5 \pm 1.0 \pm 0.7 \pm 0.6$
ϕ	950–1100	$3.8 \pm 0.7 \pm 0.4 \pm 0.5$
High mass	> 1100	$< 2.0\,(2.2)$

$$\mathcal{B}(D^0 \to \pi^+\pi^-[e^+e^-]_{m(e^+e^-)>2m_\mu}) = (13.3 \pm 1.1 \pm 1.7 \pm 1.8) \times 10^{-7}$$

Stat. Sys. Nom.



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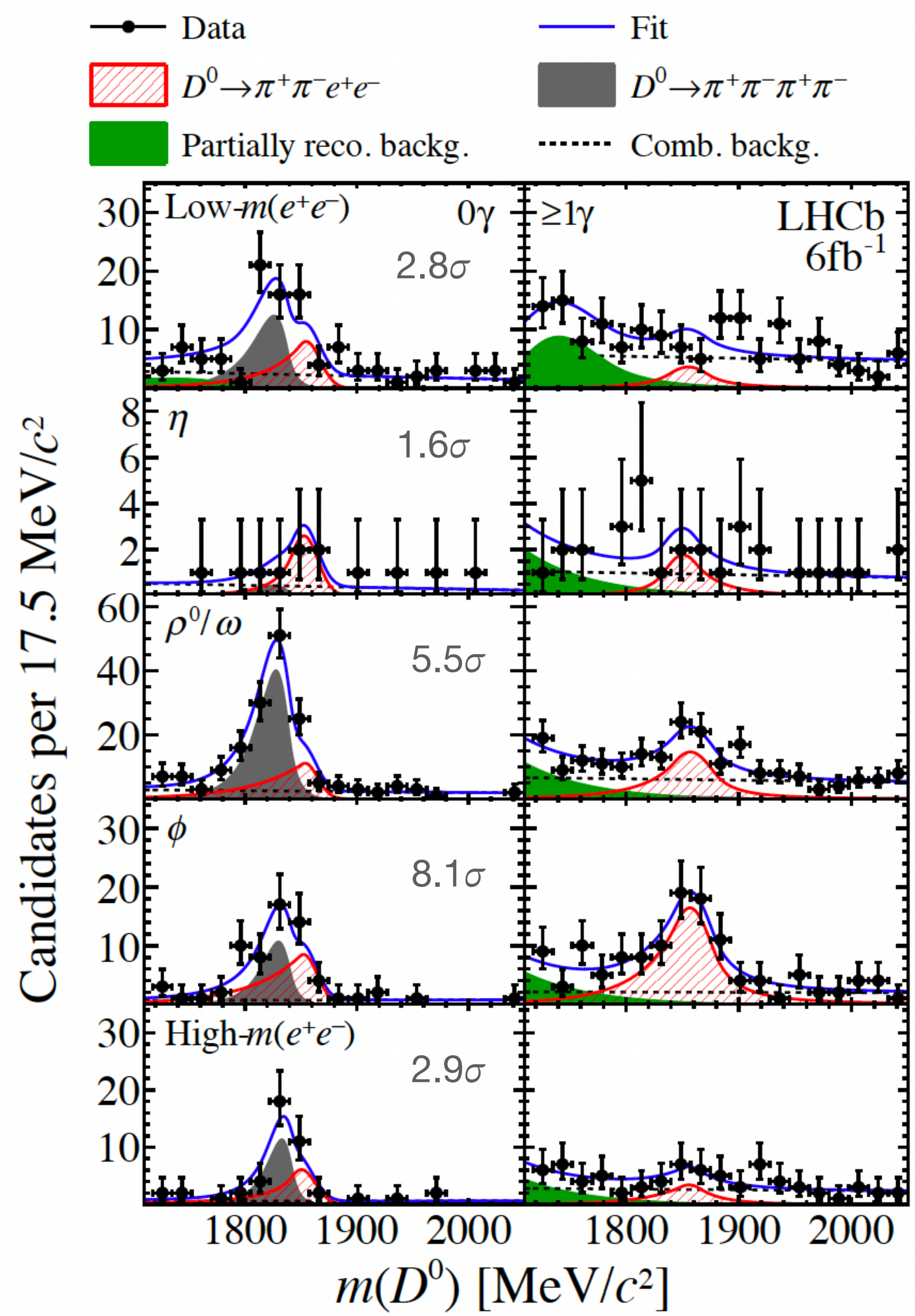
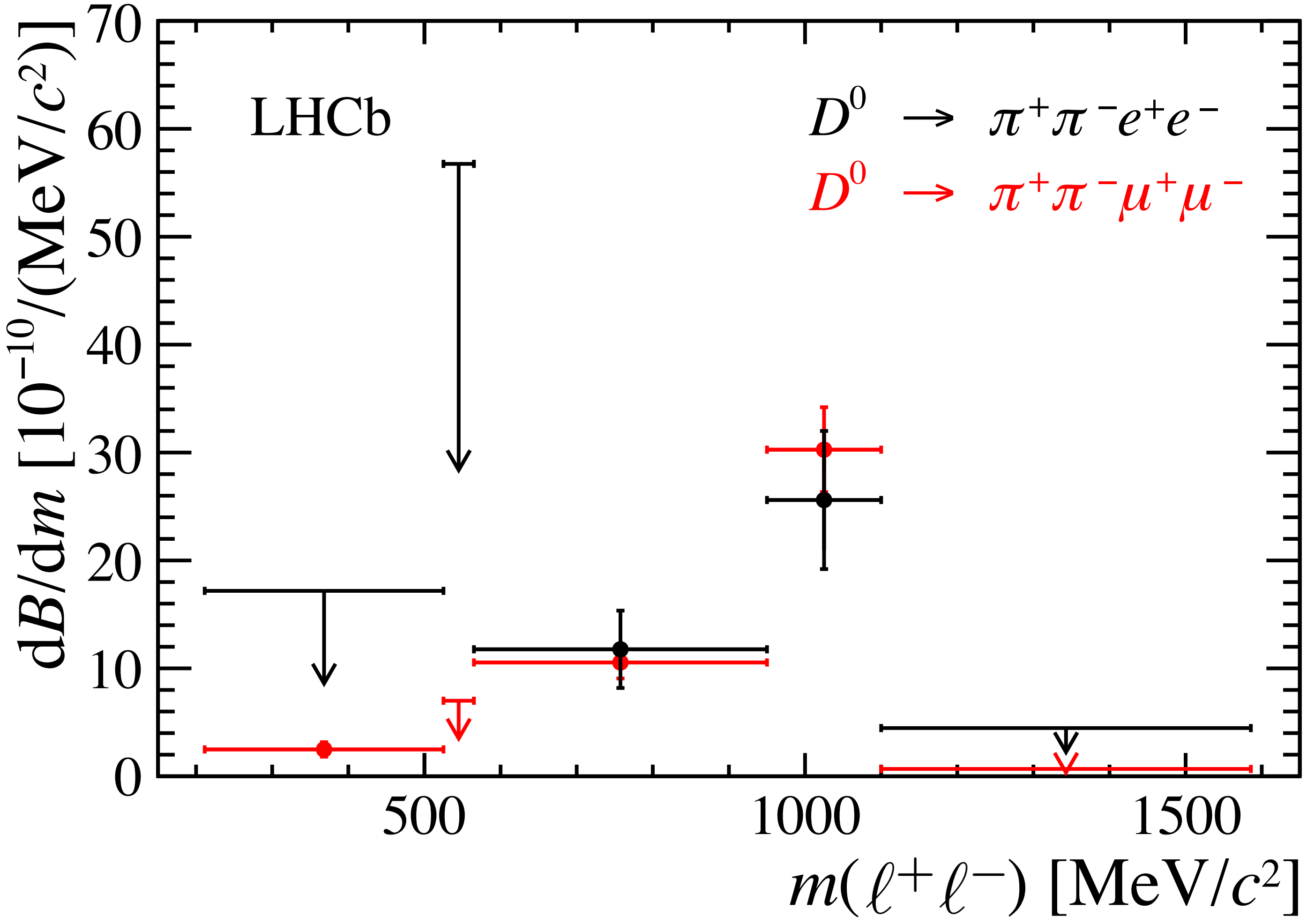


- World's best limits on $D^0 \to K^+K^-e^+e^-$

Search for $D^0 \to h^+h^-e^+e^-$

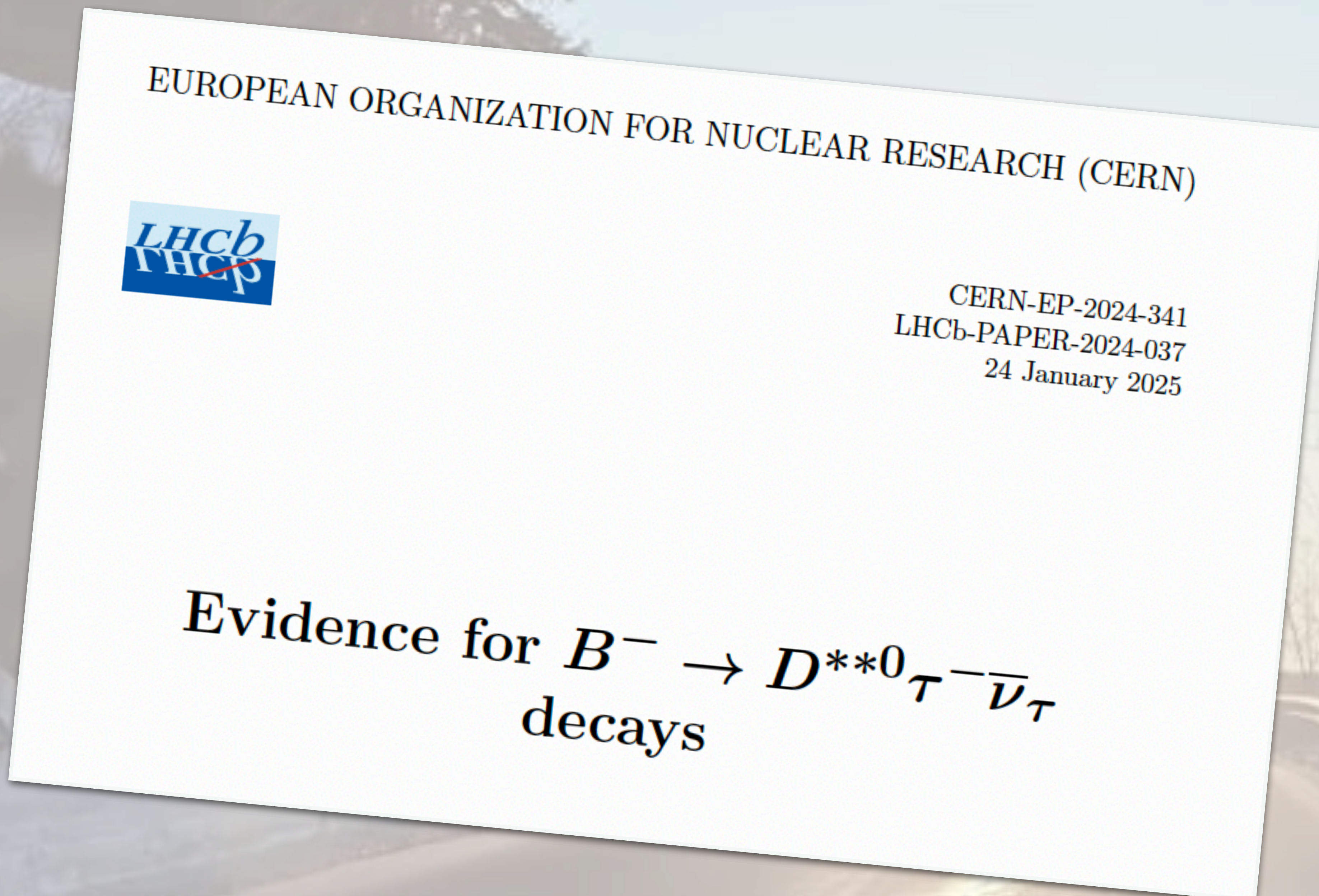
arXiv:2412.09414



Compatible with SM prediction and muon mode branching fractions

Phys. Rev. Lett. 119 (2017) 181805

arXiv:2501.14943


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

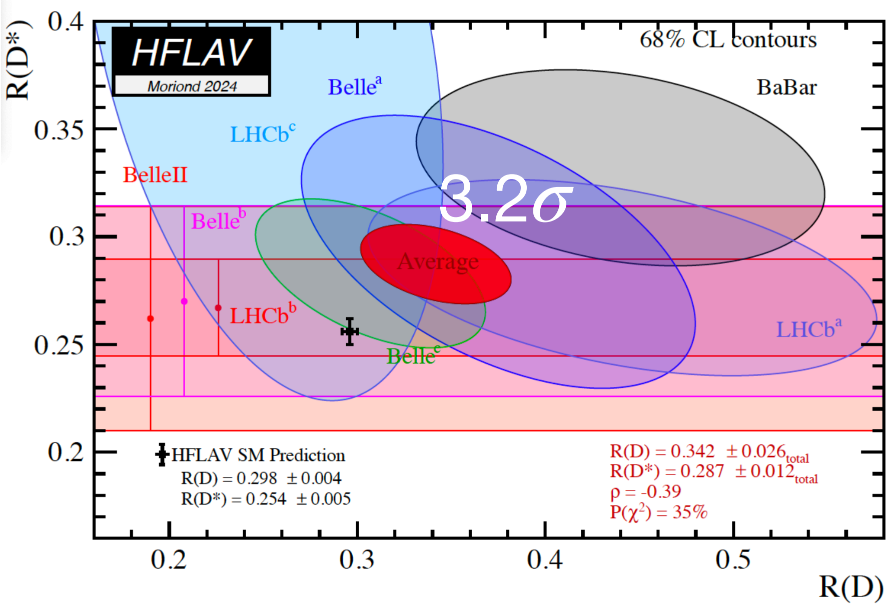
CERN-EP-2024-341
LHCb-PAPER-2024-037
24 January 2025

Evidence for $B^- \to D^{**0}\tau^-\overline{\nu}_\tau$ decays

Evidence for $B^- \to D^{**0}\tau^-\bar{\nu}$ arXiv:2501.14943

- Semi-leptonic $H_b \to H_c \ell \nu$ decays complementing field to look for BSM effects in $b \to c\ell\nu$ transitions

$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau\nu)}{\mathcal{B}(H_b \to H_c \mu\nu)}$$



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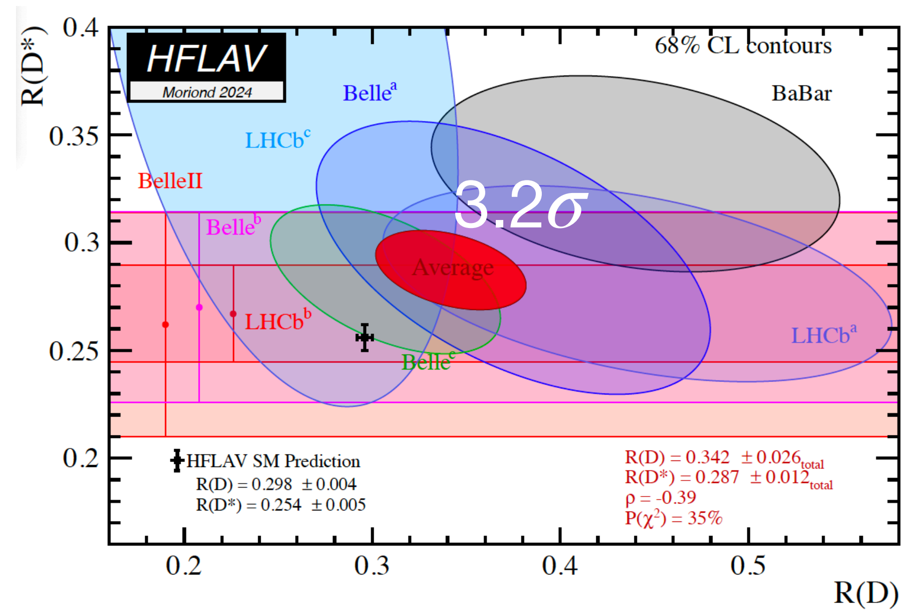
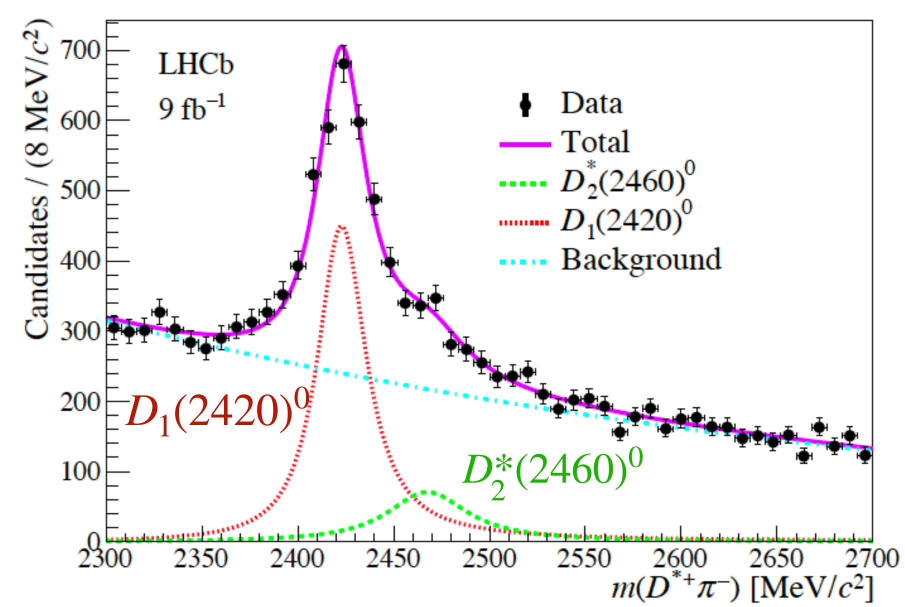


- Important systematic uncertainty in $R(D^*)$ from feed down of $B^- \to D^{**0}\ell^-\bar{\nu}$ decays

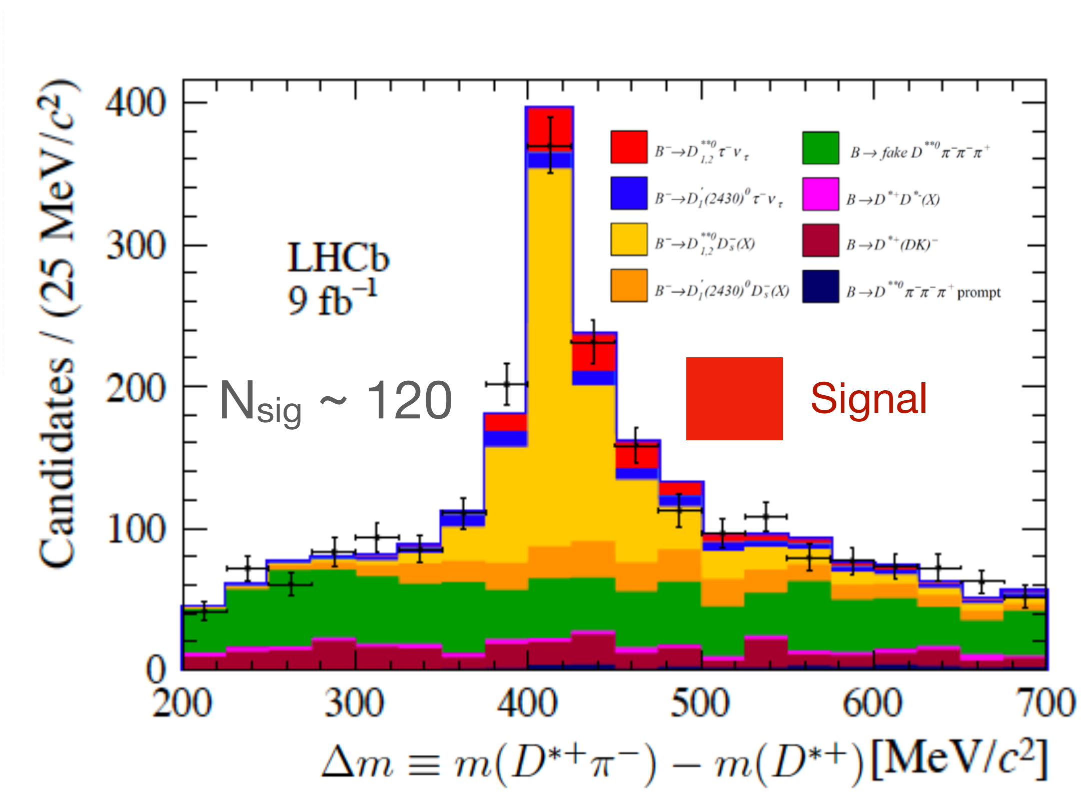
$$D^{**0}_{1,2} = D_1(2420)^0, D_2^*(2460)^0$$

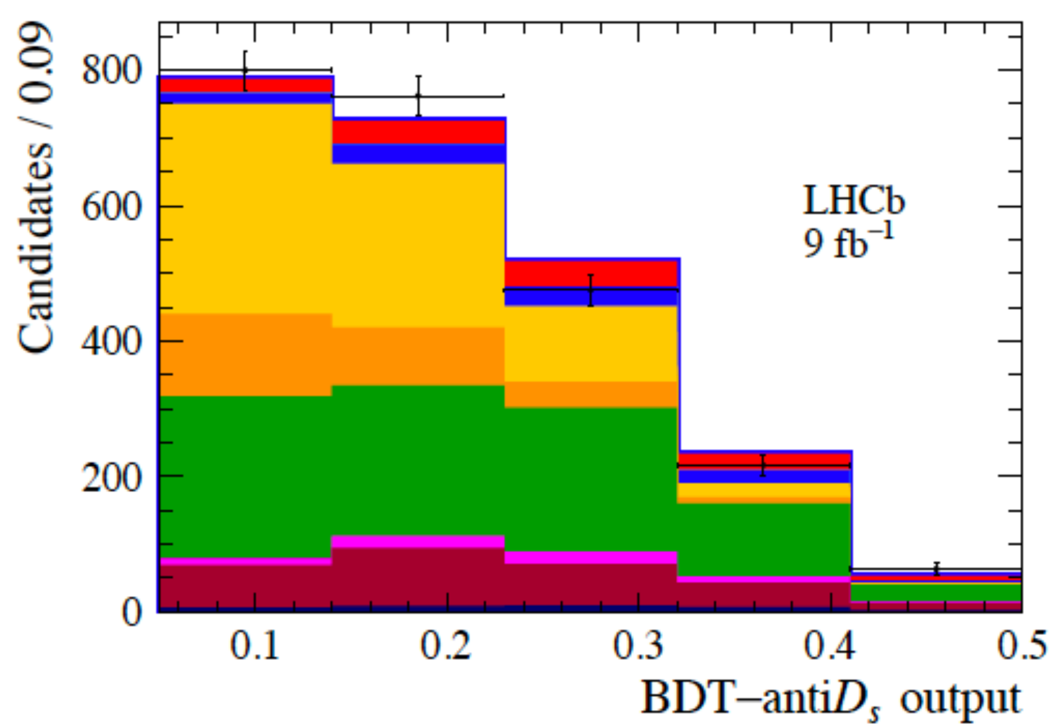


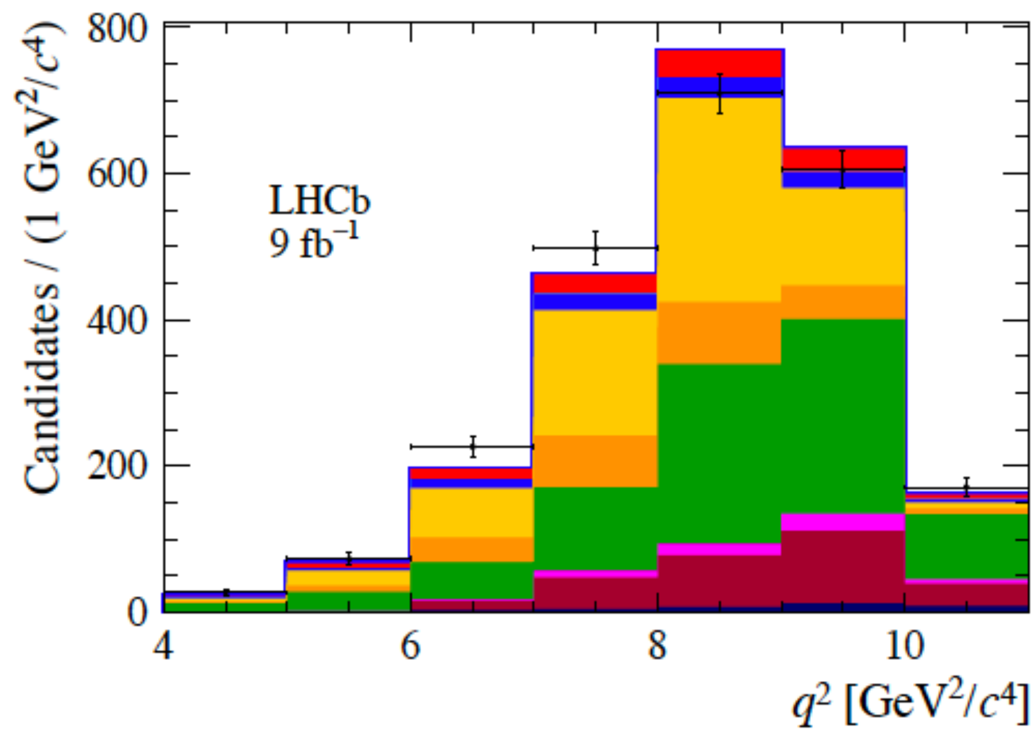
- Now: First measurement of $R(D^{**0}_{1,2})$ and $\mathscr{B}(B^- \to D^{**0}_{1,2}\tau^-\bar{\nu})$ with Run I and Run II data

- Very complex analysis: 3D fit (q^2, BDT, Δm)

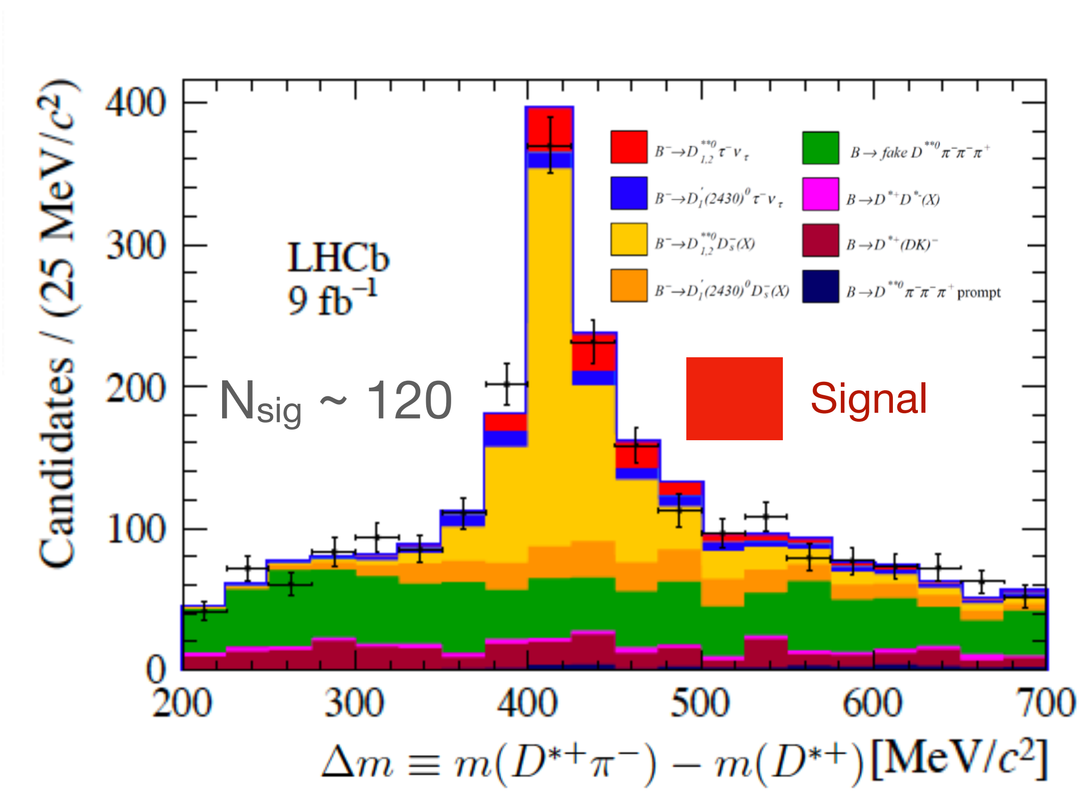
Evidence for $B^- \to D^{**0}\tau^-\bar{\nu}$ arXiv:2501.14943







Evidence for $B^- \to D^{**0}\tau^-\bar{\nu}$ arXiv:2501.14943



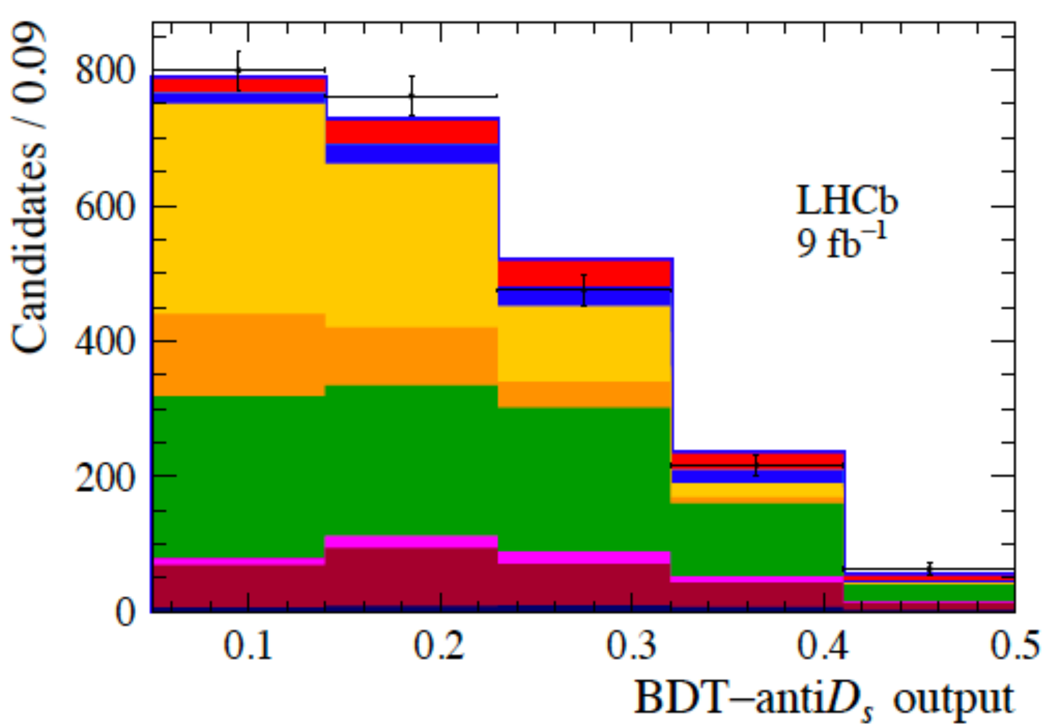
Results

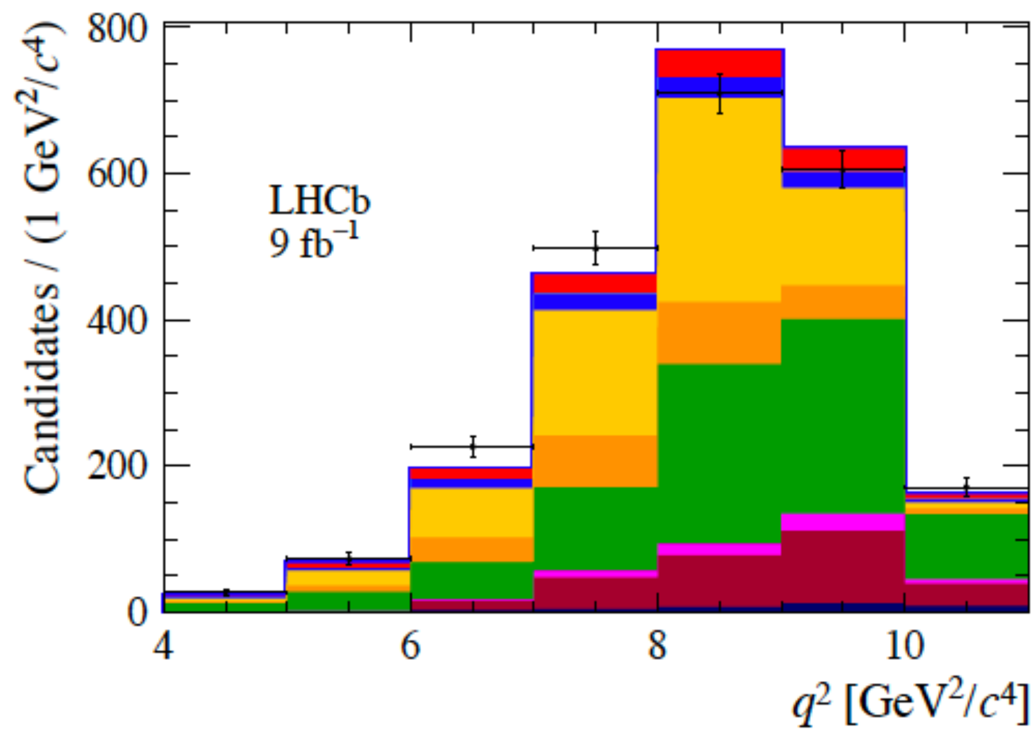
- First evidence (3.5σ) of $B^- \to D_{1,2}^{**0}\tau^-\bar{\nu}$

$$\frac{\mathcal{B}(B^- \to D_{1,2}^{**0}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(B^- \to D_{1,2}^{**0}D_s^{(*)-})} = 0.19 \pm 0.04\,(\mathrm{stat}) \pm 0.02\,(\mathrm{syst})$$

$$\mathcal{R}(D_{1,2}^{**0}) = 0.13 \pm 0.03\,(\mathrm{stat}) \pm 0.01\,(\mathrm{syst}) \pm 0.02\,(\mathrm{ext})$$

In good agreement (<1σ) with SM





Summary and conclusion

- LHCb: >150 papers on rare (b,c,s) and semileptonic decays
  - Many 'new' and 'first' in this talk (only results submitted since last Dec!)
  - Big picture remains unchanged:
    - Angular observables in $B^0 \to K^{*0} e^+ e^-$ confirm muon mode results
    - New measurements confirming LU in b→s$\ell\ell$ and b→c$\ell\nu$ transitions
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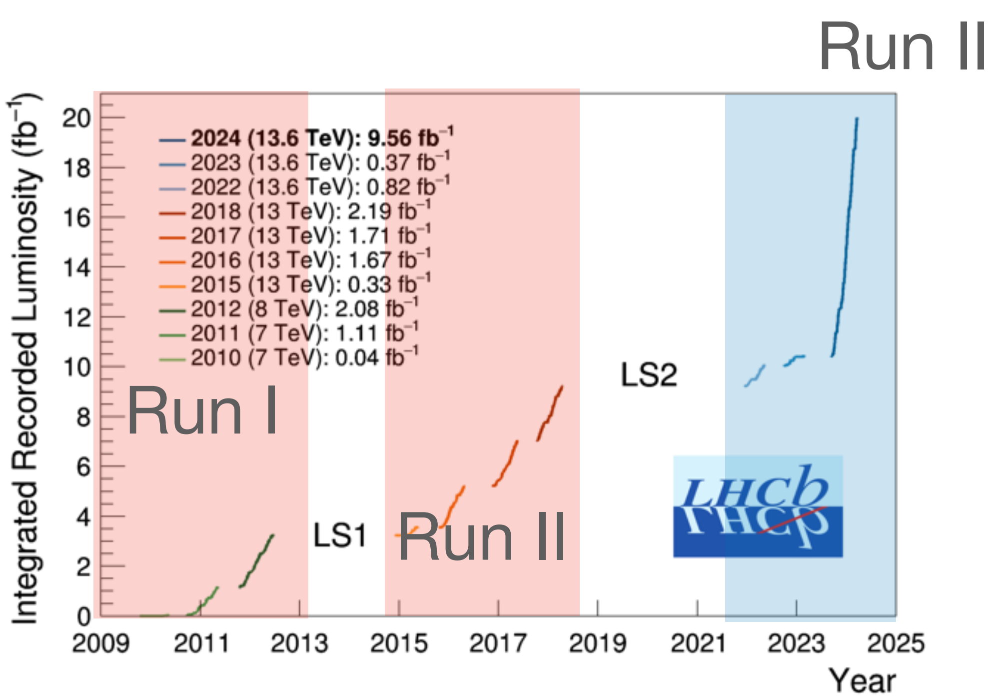


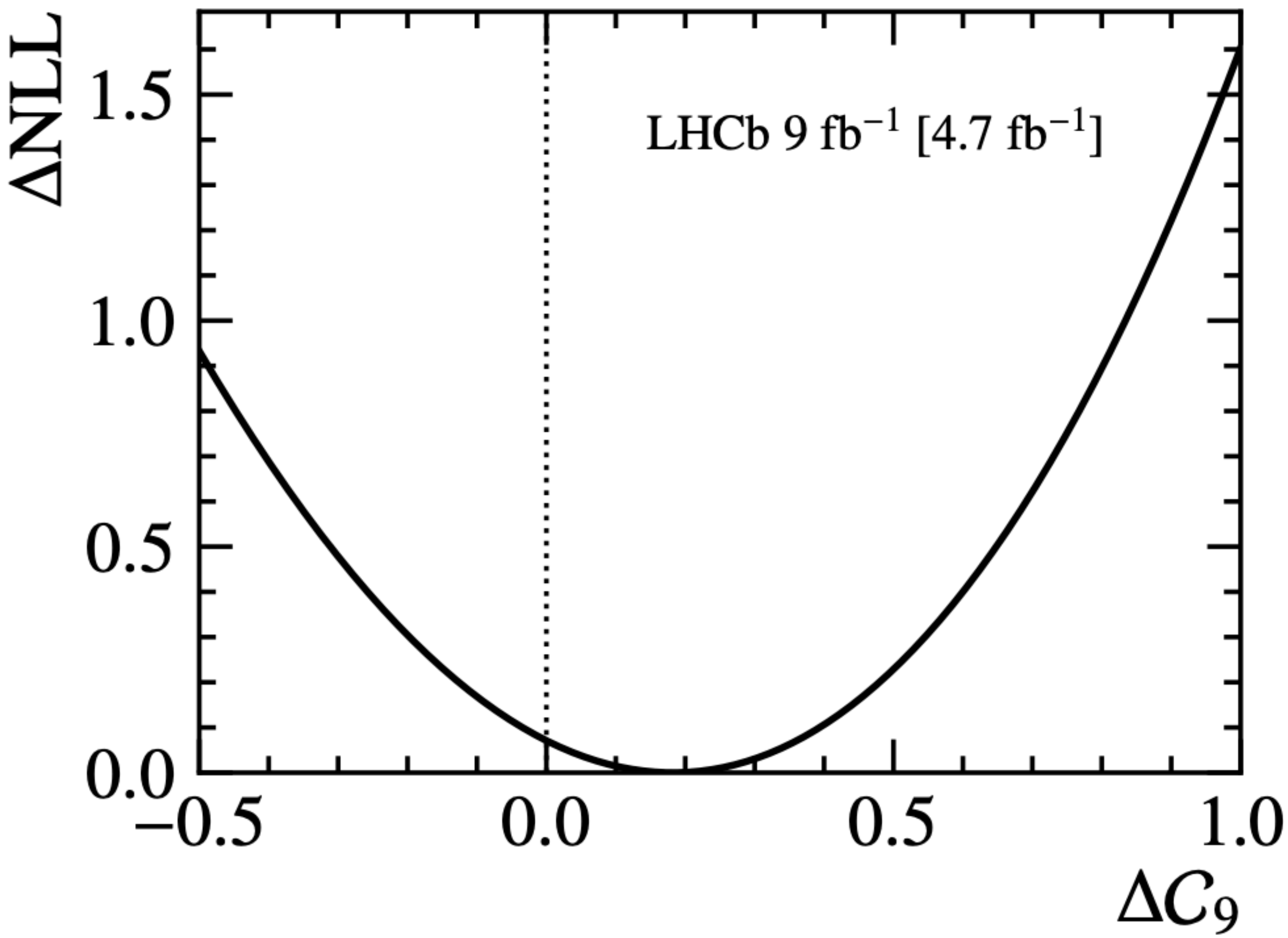
- Most results shown today statistically limited
  - New detector since ’22, expect first results with Run III data soon

LHCb is ideally suited to keep searching for NP beyond the TeV scale!

Thank you!

Angular analysis $B^0 \to K^{*0} e^+ e^-$

arXiv:2502.10291



Angular analysis $B^0 \to K^{*0}e^+e^-$

arXiv:2502.10291

Systematic uncertainties

Table 2: Summary of the systematic uncertainties on the P-basis angular observables. All values are given as fractions of the statistical uncertainties.

Source	F_L	P_1	P'_4	P'_5	P_2	P'_6	P'_8	P_3
Comb and DSL backgrounds	0.69	0.87	0.49	0.61	0.95	0.24	0.81	0.71
Part. reco. background	0.21	0.17	0.14	0.22	0.20	0.06	0.07	0.16
Misid. had. background	0.38	0.57	0.18	0.26	0.34	0.41	0.17	0.36
Effective acceptance	0.39	0.49	0.52	0.51	0.55	0.62	0.50	0.40
Signal mass modelling	0.26	0.16	0.14	0.18	0.31	0.06	0.06	0.15
J/ψ backgrounds	0.18	0.13	0.06	0.11	0.29	0.04	0.04	0.12
S-wave component	0.35	0.10	0.18	0.11	0.29	0.21	0.01	0.20
B^+ veto	0.50	0.41	0.28	0.37	0.52	0.22	0.21	0.37
Fit bias	0.01	0.00	0.04	0.03	0.08	0.02	0.02	0.02
Total	1.14	1.25	0.84	0.97	1.38	0.84	0.99	1.02

Angular analysis $B_s^0 \to \phi e^+ e^-$

arXiv:2411.10219

Systematic uncertainties

Source of systematic	$A_T^{(2)}$	$A_T^{\mathcal{I}mCP}$	$A_T^{\mathcal{R}eCP}$	F_L
$\Delta\Gamma_s/\Gamma_s$	0.008	<0.001	<0.001	<0.001
Corrections to simulation	0.002	<0.001	<0.001	0.010
Acceptance function modelling	<0.001	<0.001	0.001	0.002
Simulation sample size for acceptance	0.006	0.008	0.005	0.002
Background contamination	0.009	0.014	0.004	0.006
Angles resolution	−0.005	<0.001	—	—
Total systematic uncertainty	0.014	0.016	0.006	0.012
Statistical uncertainty	0.235	0.247	0.155	0.056

Table 1: Summary of the systematic uncertainties. For comparison, the statistical uncertainties are shown in the last row of the table. The dash indicates that the parameter is not affected by the corresponding systematic.

LU in $B^+ \to K^+\pi^+\pi^-\ell^+\ell^-$

arXiv:2412.11645

Systematic uncertainties

Source	Uncertainty [%]
$r_{J/\psi}$ nonflatness	$[-1.2, +1.6]$
Efficiency calibration	$[-1.8, +2.4]$
Phase-space simulation	$[-3.0, +4.0]$
Fit bias	$[-1.1, +1.4]$
Signal lineshape	$[-1.7, +2.2]$
Leakage from resonant decays	$[-1.0, +1.4]$
Hadron-to-electron misidentification	$[-5.3, +7.1]$
Partially reconstructed background	$[-0.9, +1.2]$
Total	$[-6.9, +9.2]$

Search for $D^0 \to h^+h^-e^+e^-$

arXiv:2412.09414

$m(e^+e^-)$ region	$[\mathrm{MeV}/c^2]$	$\mathcal{B}\ [10^{-7}]$
	$D^0 \to \pi^+\pi^-e^+e^-$	
Low mass	$2m_\mu$–525	$< 4.8\,(5.4)$
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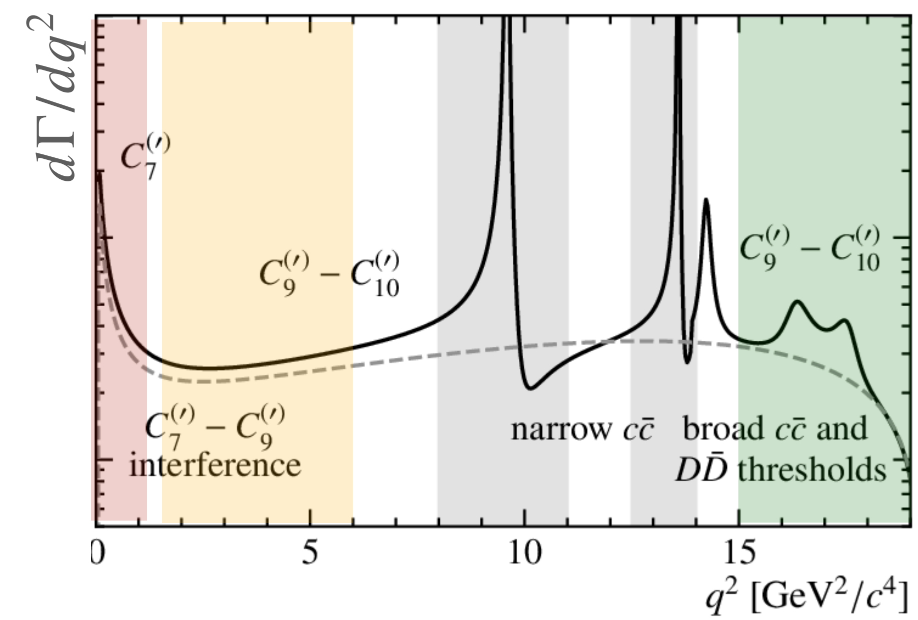
High mass	> 1100	$< 2.0\,(2.2)$
	$D^0 \to K^+K^-e^+e^-$	
Low mass	$2m_\mu$–525	$< 1.0\,(1.1)$
η	525–565	$< 0.4\,(0.5)$
ρ^0/ω	> 565	$< 2.2\,(2.5)$

LU in $B_s^0 \to \phi\ell^+\ell^-$

arXiv:2410.13748

- First LU test in b → s transitions using B_s^0 mesons
  - Conceptually very similar to measurement of $R_{K\pi\pi}$
  - Analysis in 3 q^2 bins using full Run I + Run II
    - Low [0.1, 1.1] GeV^2
    - Central [1.1, 6.0] GeV^2
    - High [15.0, 19.0] GeV^2



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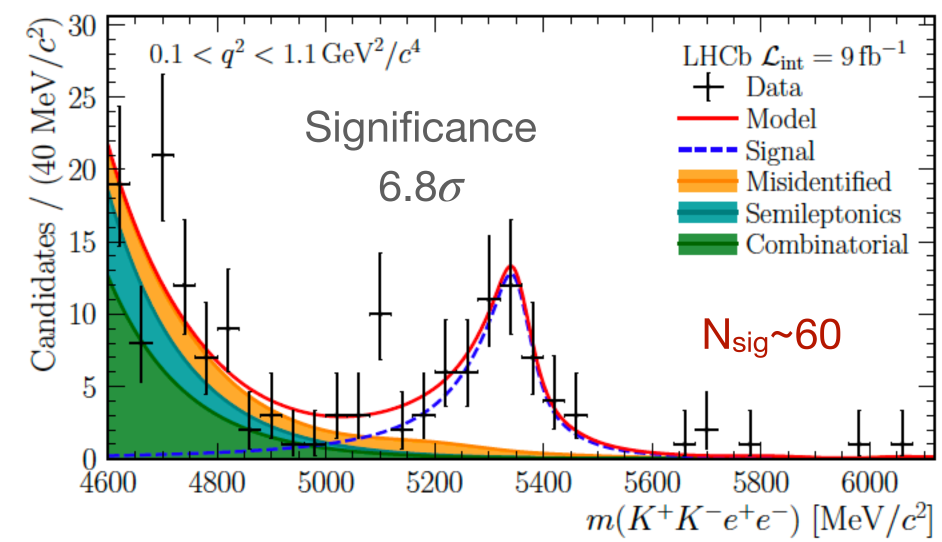
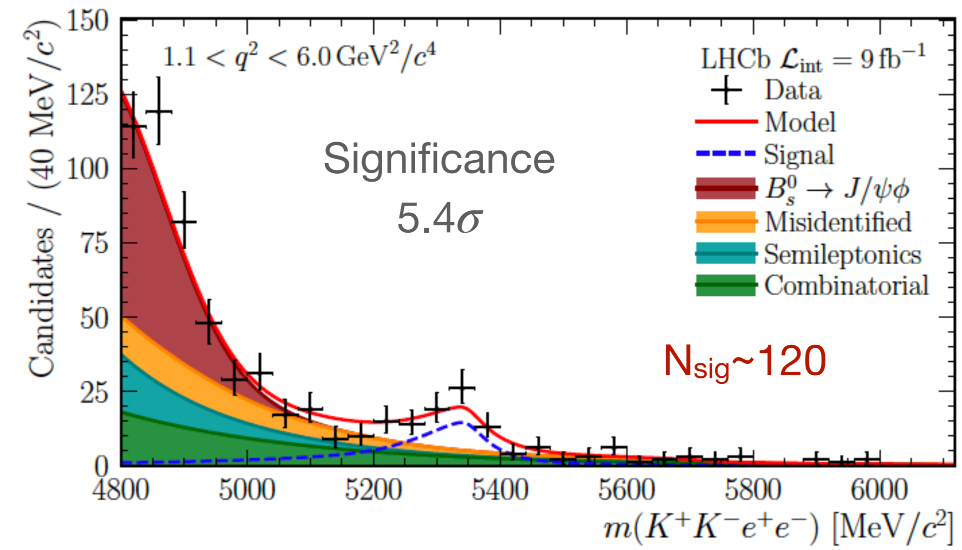
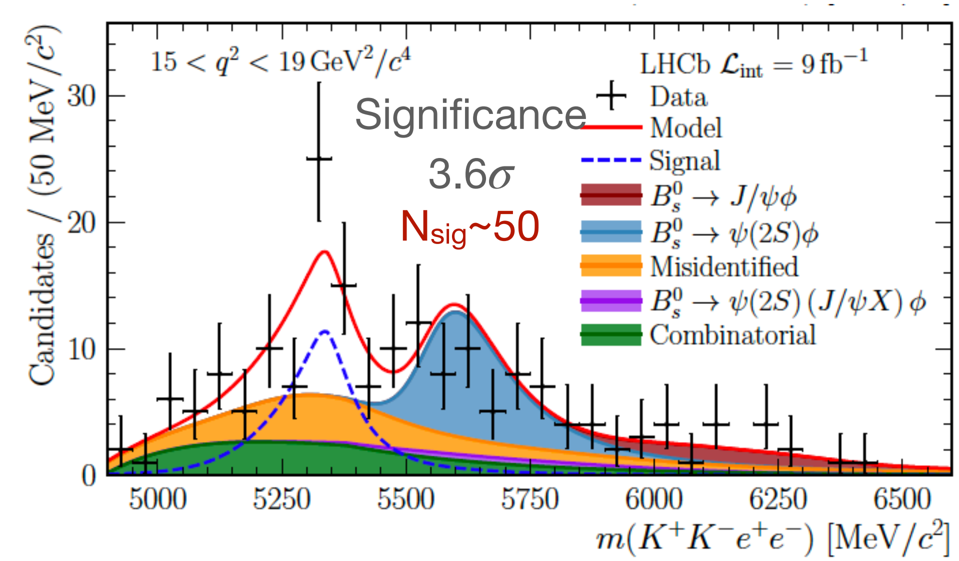
  - Together with arXiv:2411.10219 first observation of $B_s \to \phi e^+ e^-$



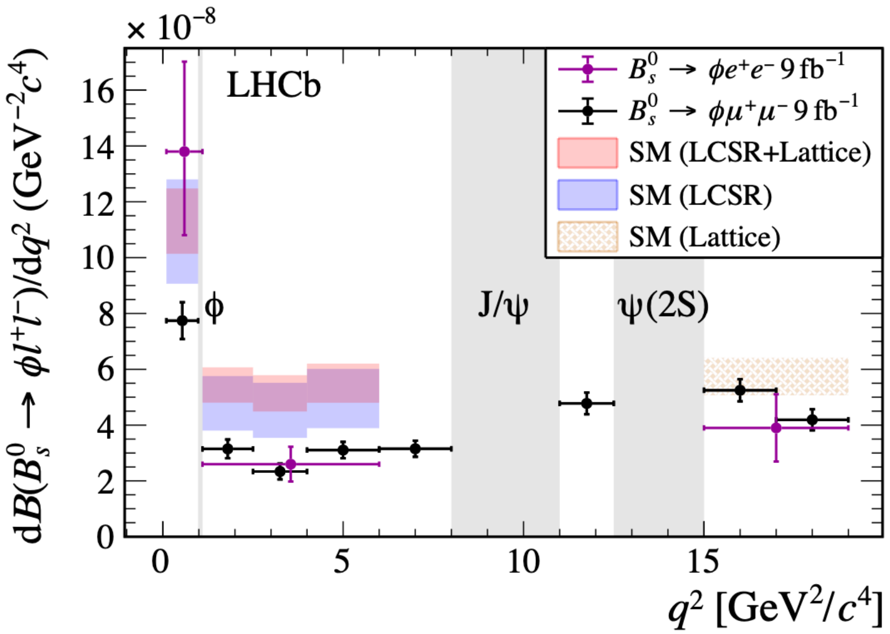




LU in $B_s^0 \to \phi\ell^+\ell^-$

arXiv:2410.13748

Results



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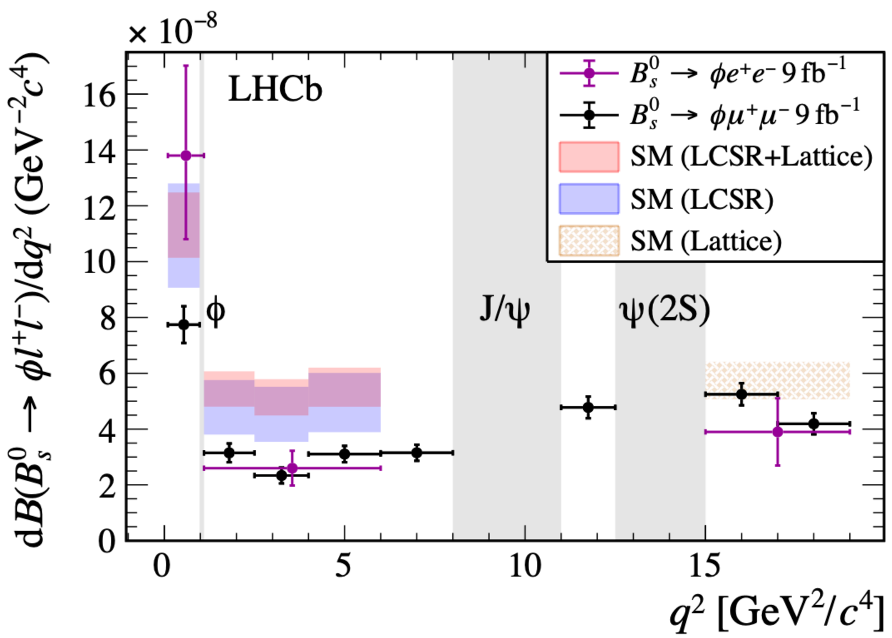
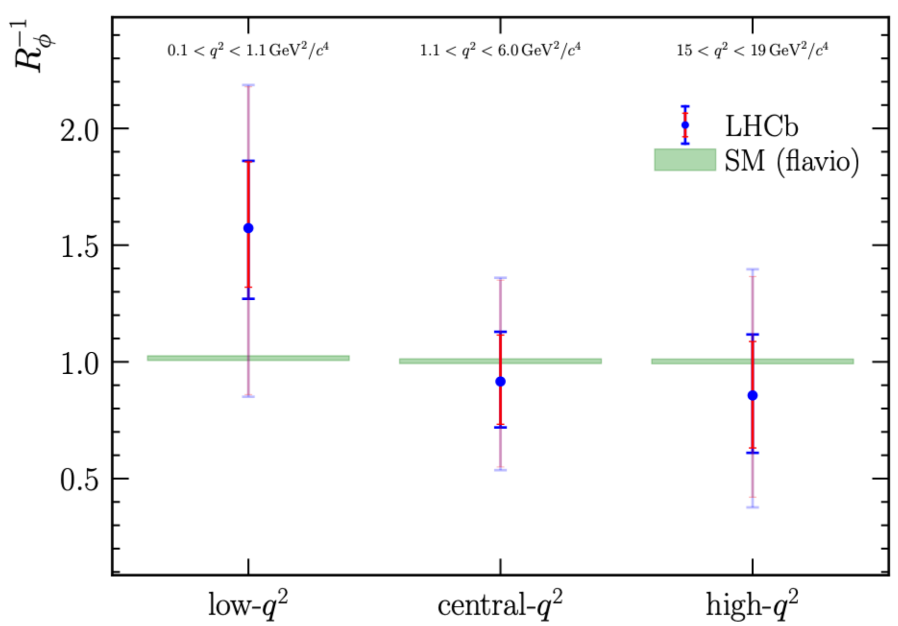


q^2 [GeV$^2/c^4$]	R_ϕ^{-1}
$0.1 < q^2 < 1.1$	$1.57\,^{+0.28}_{-0.25} \pm 0.05$
$1.1 < q^2 < 6.0$	$0.91\,^{+0.20}_{-0.19} \pm 0.05$
$15.0 < q^2 < 19.0$	$0.85\,^{+0.24}_{-0.23} \pm 0.10$

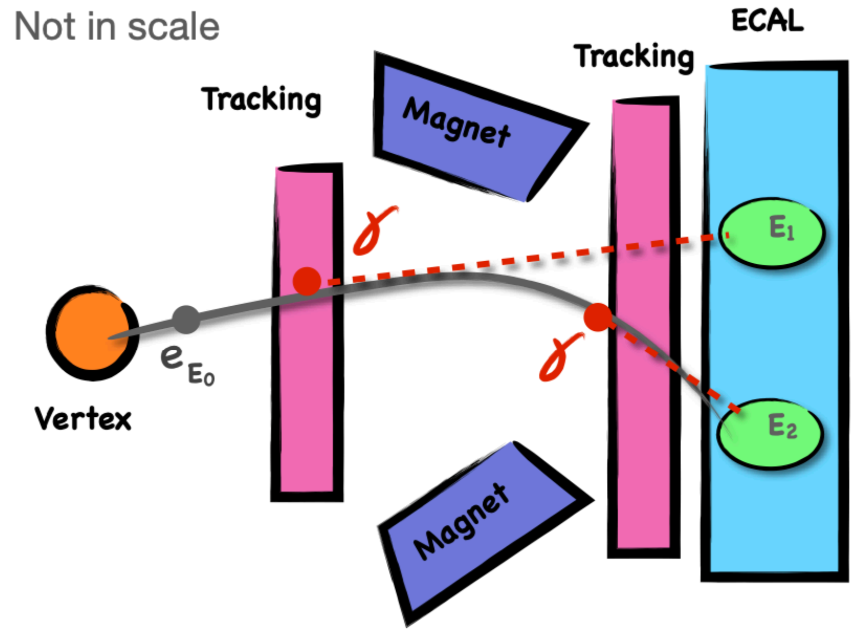


In agreement with muon mode and the SM expectation

Electrons vs Muons at LHCb

- Lower trigger efficiencies: relative high energy thresholds due to high occupancy in calorimeter
- Reduced Resolution: electrons emit Bremsstrahlung when interacting with detector material/B field
- More background: partially reconstructed decays, mis-identified background,…

S. Celani, Talk at LHCb Implications Workshop (2024)



A. Scarabotto, PhD thesis, 04323454 (2023)