Rare and very rare decays at LHCb

Alessandro Scarabotto
On behalf of the LHCb collaboration

La Thuile, Italy

59th Rencontres de Moriond 2025

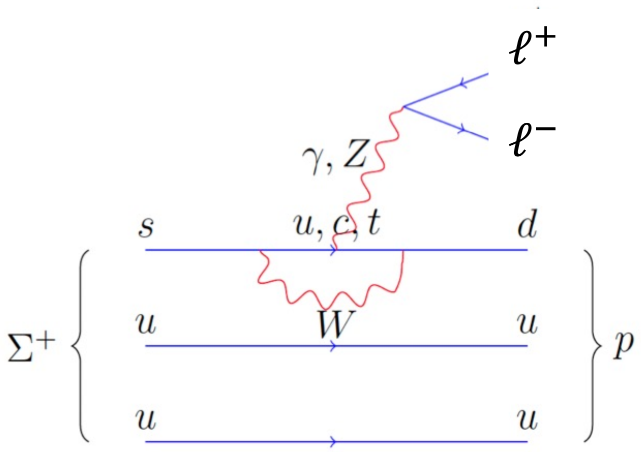
24th March 2025

technische universität dortmund

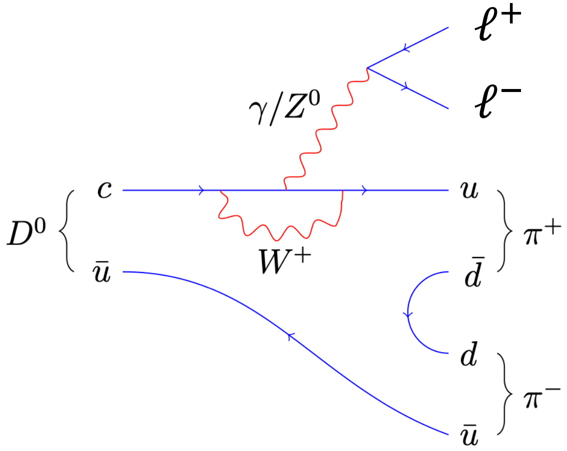
Why study rare decays?

- Receive contributions from flavor-changing neutral-current (FCNC) processes
- FCNC cannot proceed at tree level in the SM, but only through highly suppressed loops which makes them ideal probes for Beyond-SM physics

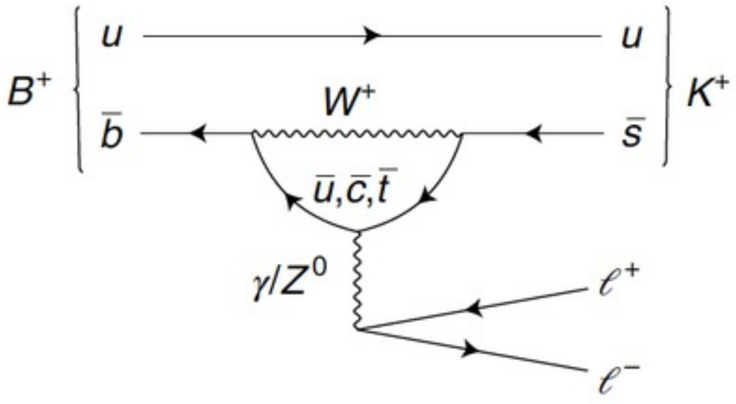
strange



charm



beauty



Why study rare decays?

- Receive contributions from flavor-changing neutral-current (FCNC) processes
- FCNC cannot proceed at tree level in the SM, but only through highly suppressed loops which makes them ideal probes for Beyond-SM physics
- Study **rare** (BF < 10^{-6}) and **very rare** (BF < 10^{-9} and forbidden in SM) decays
- At LHCb, many different channels studied:
  - Semi-leptonic decays
  - Fully leptonic decays, i.e. $\mathrm{B_s} \to \ell^+\ell^-$, $\mathrm{D}^0 \to \ell^+\ell^-$, …
  - Lepton flavour violating modes probing μe, $\mu\tau$ and τe couplings

Why study rare decays?

- Receive contributions from flavor-changing neutral-current (FCNC) processes
- FCNC cannot proceed at tree level in the SM, but only through highly suppressed loops which makes them ideal probes for Beyond-SM physics
- Study **rare** (BF < 10^{-6}) and **very rare** (BF < 10^{-9} and forbidden in SM) decays
- At LHCb, many different channels studied:
  - **Semi-leptonic decays → in charm and strange**
  - Fully leptonic decays, i.e. $B_s \to \ell^+\ell^-$, $D^0 \to \ell^+\ell^-$, …
  - **Lepton flavour violating modes probing** μe, $\mu\tau$ and **τe couplings**

Today

More measurements in FCNC rare beauty presented by Carla, Lorenzo and Marie

BSM searches

How to look for New Physics?

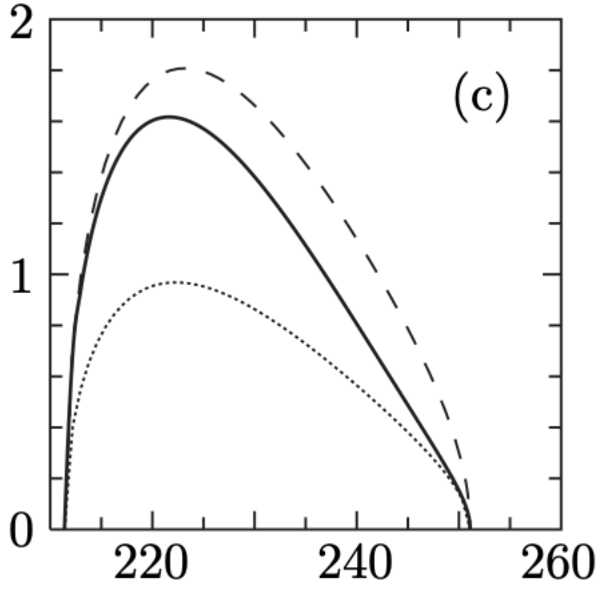
1. Measurements of branching fraction
   - as function of $q^2 (= m^2_{\ell\ell})$

BSM searches

How to look for New Physics?

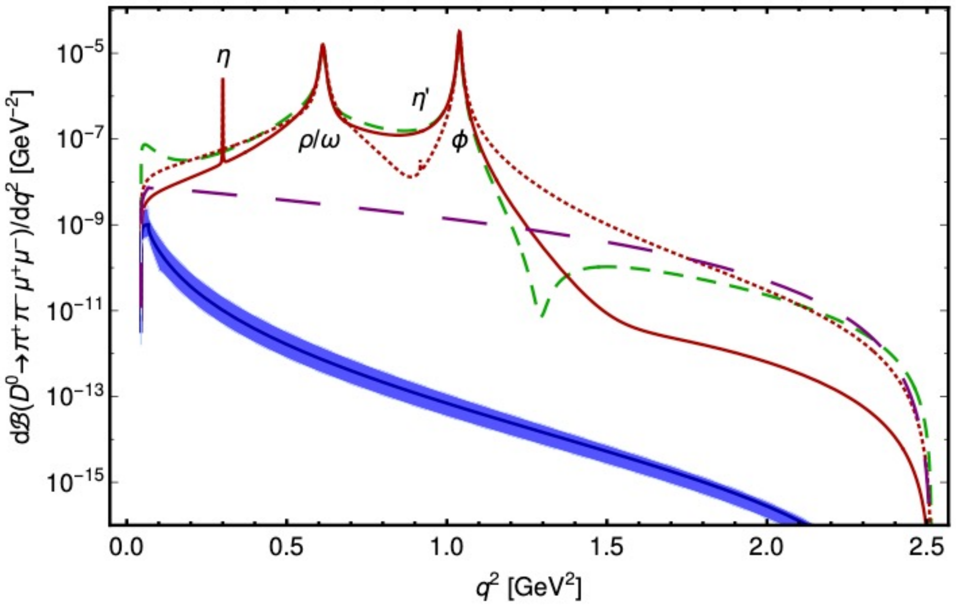
1. Measurements of branching fraction
   - as function of q^2 → long distance contributions: challenge for rare strange/charm

$\Sigma^+ \to p\,\mu^+\mu^-$



PRD 72, 074003 (2005)

$D^0 \to \pi^+\pi^-\mu^+\mu^-$



FCNC component
LD component
LD different model
NP model (dashed)

PRD 98, 035041 (2018)

BSM searches

How to look for New Physics?

1. Measurements of branching fraction
   - as function of q^2 (= $m^2_{\ell\ell}$)
   - lepton flavour violating modes

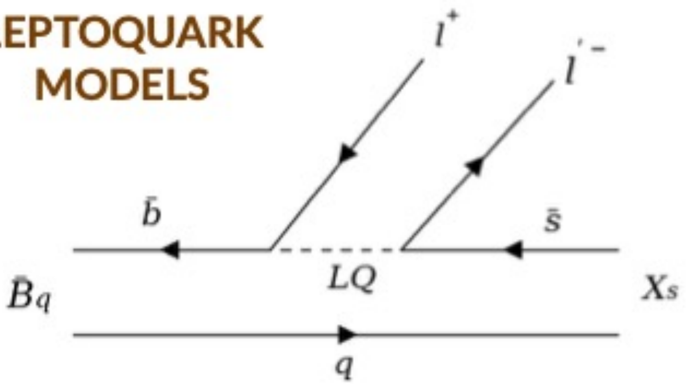
Standard Model with neutrino oscillations enables lepton flavour transitions

$$BR \propto \frac{\Delta m^2_{ij}}{M^2_W} \xrightarrow{\Delta m^2_{13} \approx 2.6 \times 10^{-3} eV} 10^{-50}$$

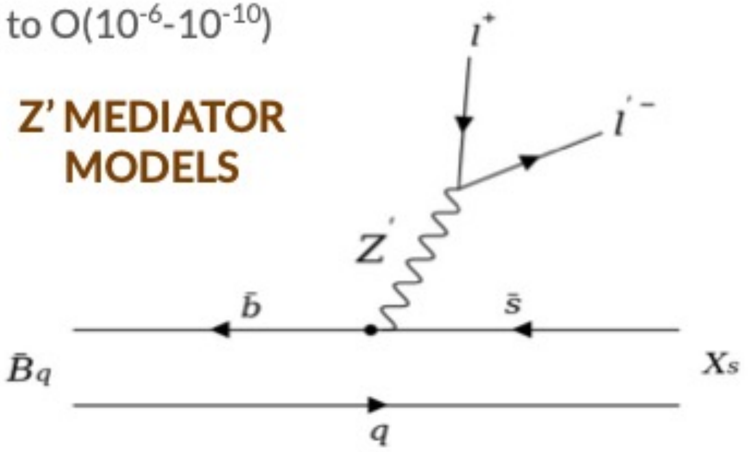
(10^{-54} for μ-e)

Predicted BR up to $O(10^{-6}$-$10^{-10})$

LEPTOQUARK MODELS



Z' MEDIATOR MODELS



P.Rept. 641 (2016), PRD 92, 054013 (2015) , R. N.Cimento, Vol. 41 (2018)71

BSM searches

How to look for New Physics?

1. Measurements of branching fraction
   - as function of q^2 (= $m^2_{\ell\ell}$)
   - lepton flavour violating modes
2. CPV and angular analysis
3. Lepton flavour universality

$$R^D_{P_1,P_2} = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(D\to P_1 P_2 \mu^+\mu^-)}{dq^2}}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(D\to P_1 P_2 e^+ e^-)}{dq^2}}$$

BSM searches

How to look for New Physics?

1. Measurements of branching fraction
   - as function of q^2 (= $m^2_{\ell\ell}$)
   - lepton flavour violating modes
2. CPV and angular analysis
3. Lepton flavour universality

$$R^D_{P_1,P_2} = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(D \to P_1 P_2 \mu^+\mu^-)}{dq^2}}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(D \to P_1 P_2 e^+ e^-)}{dq^2}}$$

- New LHCb measurements presented today:
  - Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays — LHCb-CONF-2024-002 — Rare strange
  - Search for $B^0 \to K^{*0}\,\tau^\pm e^\mp$ decays — LHCb-PAPER-2025-005* — Rare beauty
  - CP and angular for $\Lambda_c^+ \to p\,\mu^+\mu^-$ decays — arXiv:2502.04013 — Rare charm
  - Search for $D^0 \to h^+h^-e^+e^-$ decays — arXiv:2412.09414

*in preparation

Rare strange

Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

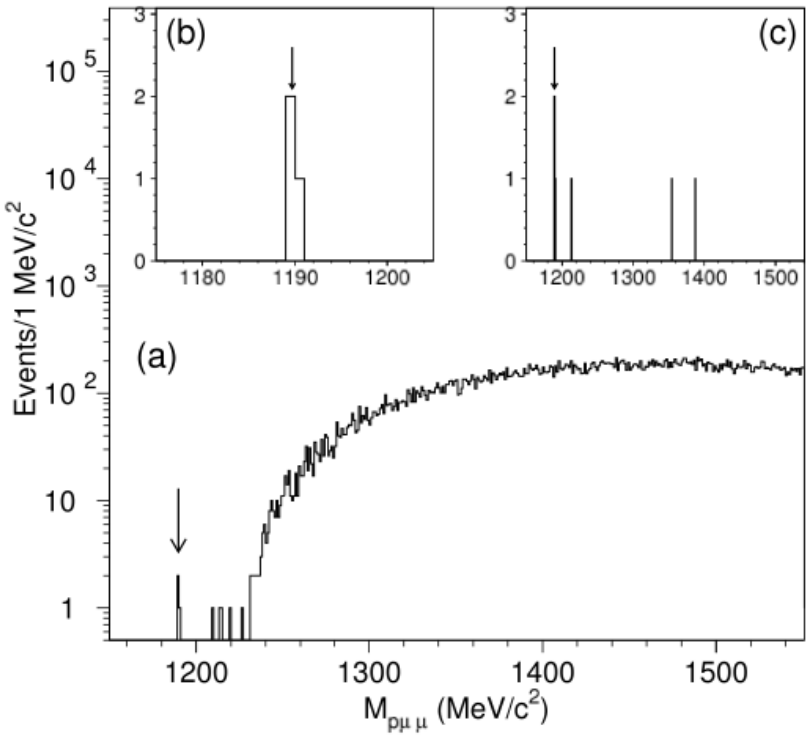
LHCb-CONF-2024-002

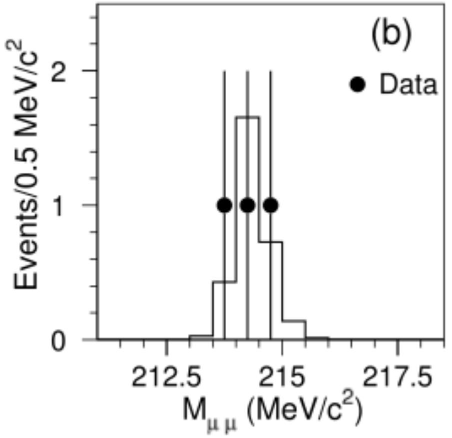
Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

- Evidence found by HyperCP experiment with 3 events in absence of background

$$B(\Sigma^+ \to p\,\mu^+\mu^-) = \left[8.6^{+6.6}_{-5.4} \pm 5.5\right]\times 10^{-8}$$

- Signal pointing to a new resonance at ~214 MeV





PRL 94:021801,2005

Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

- Evidence found by HyperCP experiment with 3 events in absence of background

$$B(\Sigma^+ \to p\,\mu^+\mu^-) = \left[8.6^{+6.6}_{-5.4} \pm 5.5\right] \times 10^{-8}$$

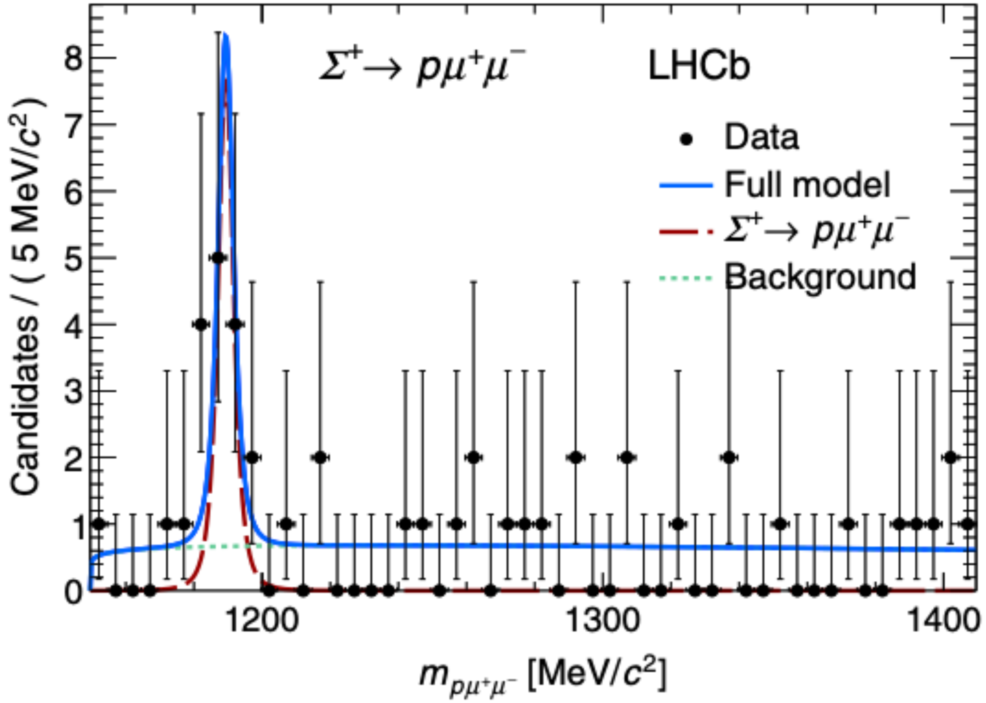
- Signal pointing to a new resonance at 214 MeV

- LHCb performed the analysis with Run1 data with an evidence at 4.1σ:

$$B(\Sigma^+ \to p\,\mu^+\mu^-) = \left[2.2^{+0.9}_{-0.8}{}^{+1.5}_{-1.1}\right] \times 10^{-8}$$

But no dimuon structure found

PRL120,221803 (2018)



Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

- Analysis repeated by LHCb with Run2 data with $5.4\ \mathrm{fb}^{-1}$
- 10-fold increased trigger efficiency compared to Run1 thanks to dedicated selections and improved PID

LHCb-PUB-2017-023

Channel	ϵ (without new lines)	ϵ (with new lines)
$K^0_\mathrm{S} \to \mu^+\mu^-$	0.0290 ± 0.0015	0.250 ± 0.004
$K^0_\mathrm{S} \to \pi^0\mu^+\mu^-$	0.026 ± 0.003	0.238 ± 0.008
$\Sigma^+ \to p\mu^+\mu^-$	0.0083 ± 0.0013	0.111 ± 0.004

x 10

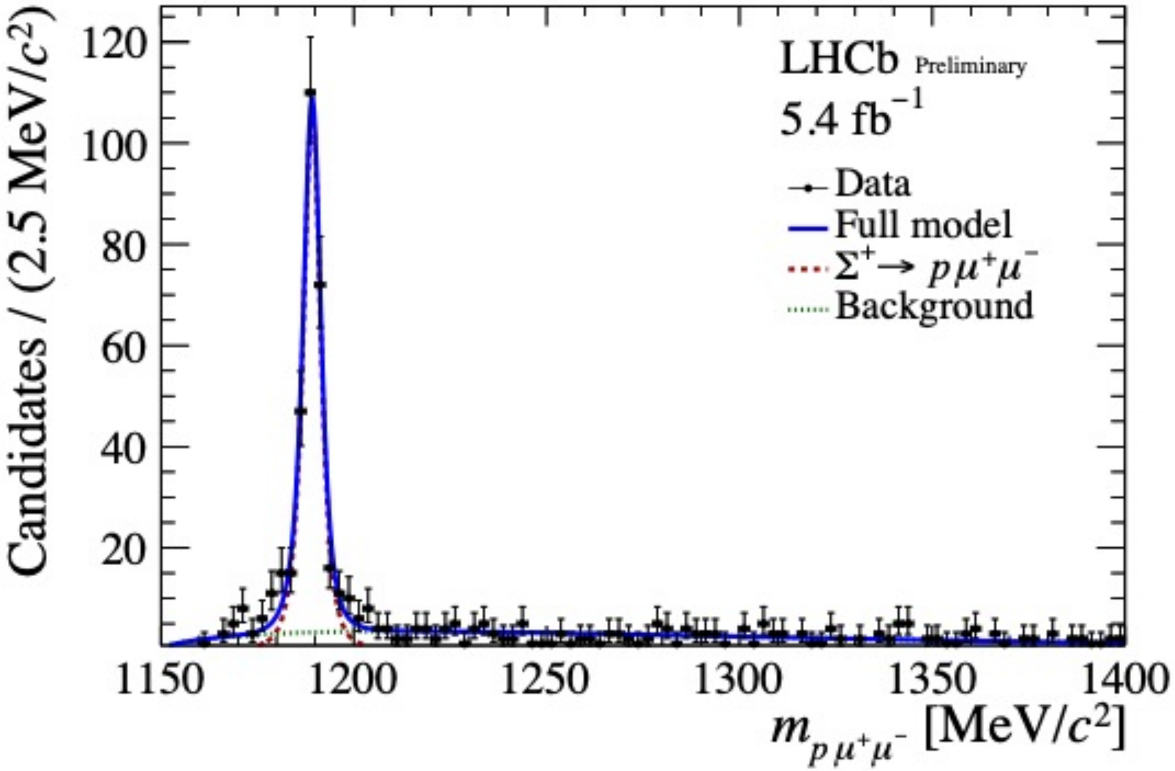
LHCb-CONF-2024-002

Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

- Analysis repeated by LHCb with Run2 data with $5.4\ \mathrm{fb}^{-1}$
- 10-fold increased trigger efficiency compared to Run1 thanks to dedicated selections and improved PID
- First observation with a signal yield:

$$N_{\Sigma^+\to p\,\mu^+\mu^-} = 279\ \pm 19$$

- **Rarest hyperon decay ever observed with a significance above 5σ!**
- Work ongoing on measurement of integrated branching fraction



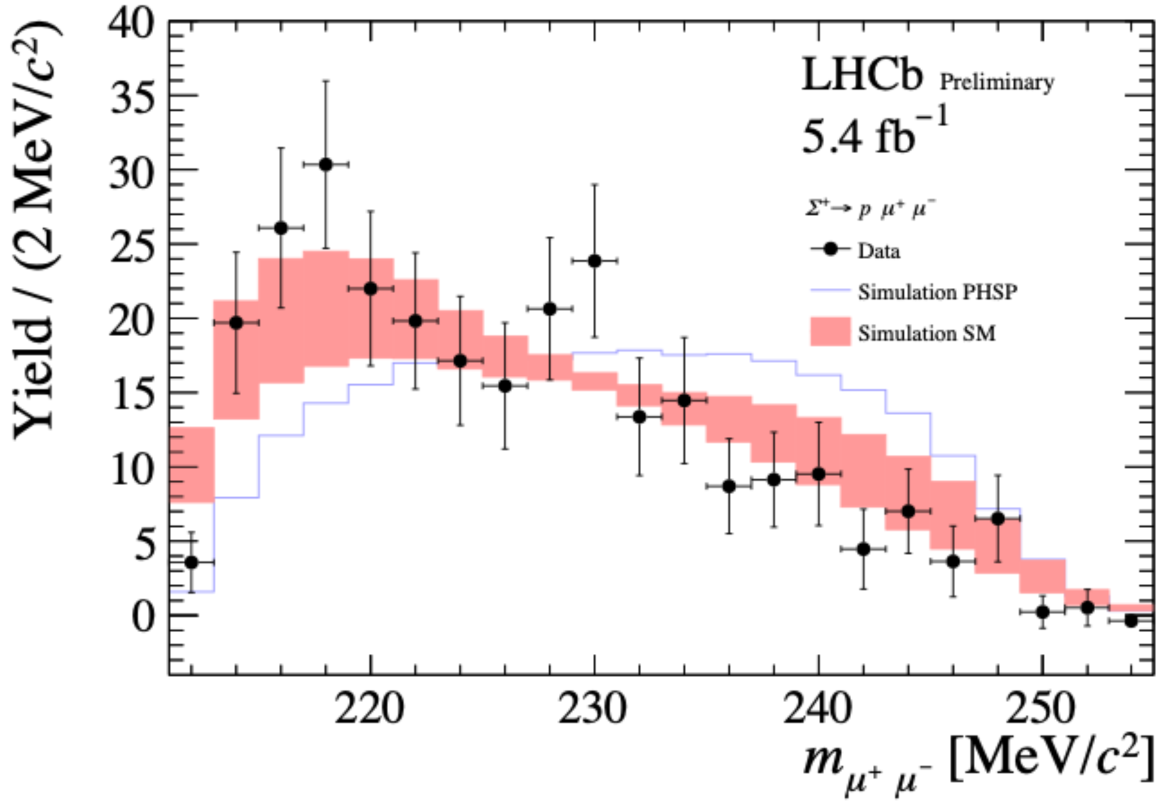
LHCb-CONF-2024-002

Search for $\Sigma^+ \to p\,\mu^+\mu^-$ decays

- Search for resonances in dimuon invariant mass distribution
- Distribution compatible with SM prediction

  JHEP 10 (2018) 040, hep-ph/2404.15268

- Scan made in the dimuon invariant mass searching for resonant structures but no significant structure found



LHCb-CONF-2024-002

Search for $B^0 \to K^{*0}\,\tau^{\pm}e^{\mp}$ decays

LHCb-PAPER-2025-004, in preparation

Search for $B^0 \to K^{*0}\,\tau^\pm e^\mp$ decays

- τe coupling already tested in B decays by Belle and BaBar experiments
- First measurement at LHCb and first probing $B^0 \to K^{*0}\,\tau^\pm e^\mp$ decays

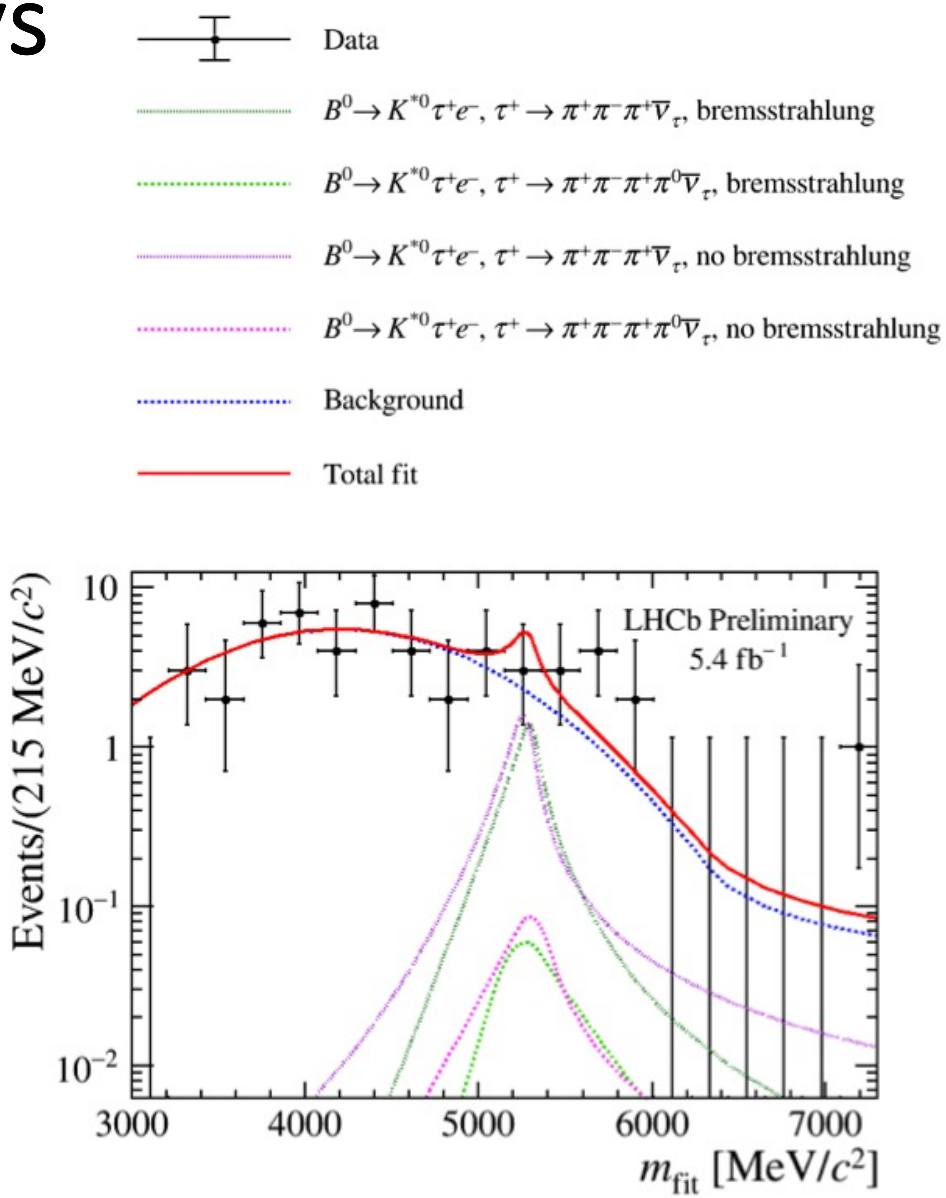
Decay	Limit (90% C.L.)	Integrated Luminosity	Experiment	
$B^0 \to \tau^\pm e^\mp$	1.6×10^{-5}	772M BB (771 fb^{-1})	Belle	[1]
$B^+ \to K^+\,\tau^- e^+$	1.53×10^{-5}	772M BB (771 fb^{-1})	Belle	[2]
$B^+ \to K^+\,\tau^+ e^-$	$1.51 \times 10^{-5} / 1.5 \times 10^{-5}$	772M BB (771 fb^{-1})/472M BB (426 fb^{-1})	Belle/BaBar	[2,3]
$B^+ \to \pi^+\,\tau^- e^+$	7.4×10^{-5}	472M BB (426 fb^{-1})	BaBar	[3]
$B^+ \to \pi^+\,\tau^+ e^-$	2.0×10^{-5}	472M BB (426 fb^{-1})	BaBar	[3]
$B^0 \to K^{*0}\,\tau^- e^+$		5.4 fb^{-1}	LHCb	
$B^0 \to K^{*0}\,\tau^+ e^-$		5.4 fb^{-1}	LHCb	

[1] Phys. Rev. D 104 (2021)
[2] Phys. Rev. Lett. 130 (2023) 261802
[3] Phys. Rev. D 86 (2012) 012004

LHCb-PAPER-2025-004, in preparation

Search for $B^0 \to K^{*0}\,\tau^{\pm}e^{\mp}$ decays

- Using 5.4 fb^{-1} data in Run2 and hadronic τ decays
- $B^0 \to D^-(K^+\pi^-\pi^-)D_s^+(K^+K^-\pi^+)$ decay as normalization channel: similar topology and abundant
- Split for charge combinations τ^+e^- and τ^-e^+
- Signal model including hadronic $\tau \to \pi^+\pi^-\pi^+(\pi^0)\bar{\nu}_\tau$ decays and if electron emitted bremsstrahlung
- Use of refitted B mass with momentum constraints



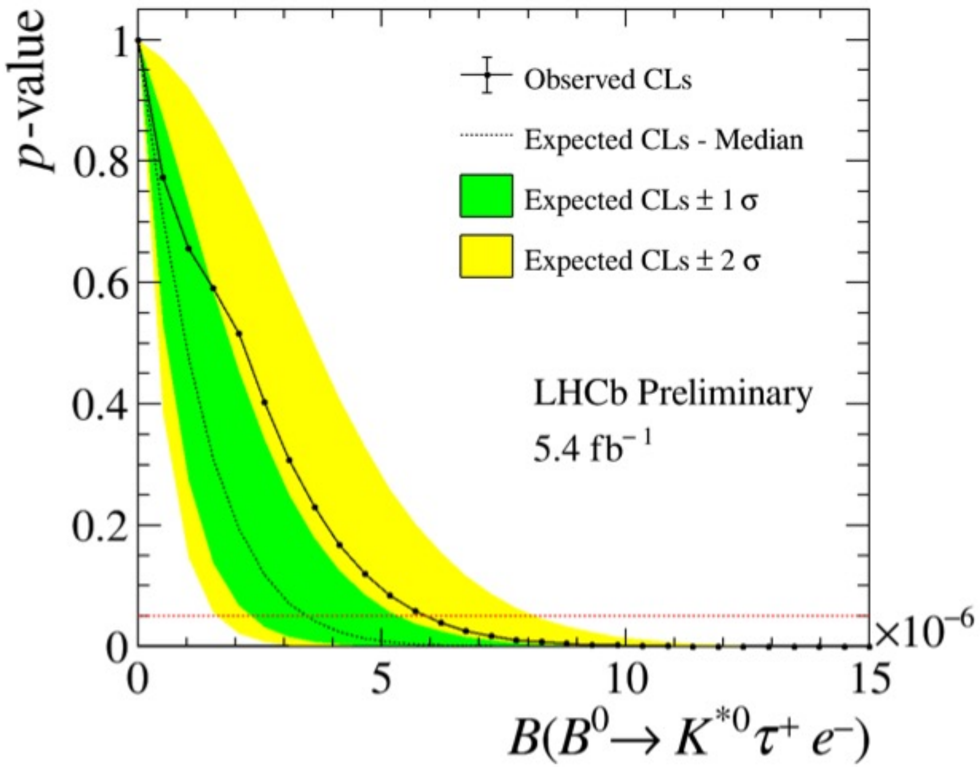
LHCb-PAPER-2025-004, in preparation

Search for $B^0 \to K^{*0}\tau^\pm e^\mp$ decays

Most stringent limit in $b \to s\tau\ell$ so far!

90 (95) % C.L.

Model	Upper limit $[10^{-6}]$	
	$B^0 \to K^{*0}\tau^- e^+$	$B^0 \to K^{*0}\tau^+ e^-$
Phase-space	5.9 (7.1)	4.9 (5.9)



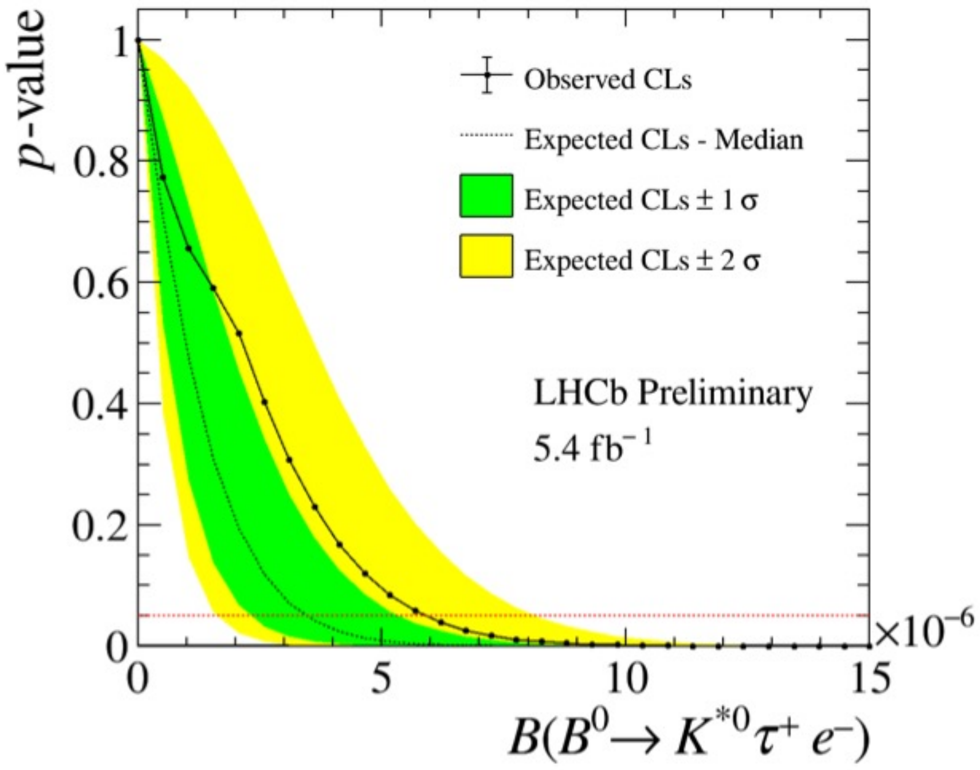
LHCb-PAPER-2025-004, in preparation

Search for $B^0 \to K^{*0}\tau^{\pm}e^{\mp}$ decays

Most stringent limit in $b \to s\tau\ell$ so far!

90 (95) % C.L.

Model	Upper limit $[10^{-6}]$ $B^0 \to K^{*0}\tau^- e^+$	Upper limit $[10^{-6}]$ $B^0 \to K^{*0}\tau^+ e^-$
Phase-space	5.9 (7.1)	4.9 (5.9)
Left-handed ($C_9^{\tau e} = -C_{10}^{\tau e} \neq 0$)	6.3 (7.7)	5.4 (6.4)
Scalar ($C_S^{\tau e} \neq 0$)	6.6 (8.0)	5.7 (6.8)



- Simulation reweighted according to two different NP models
- Projected upper limits using NP reweighted samples

P.Rept. 641 (2016), PRD 92, 054013 (2015) , R. N.Cimento, Vol. 41 (2018)71

LHCb-PAPER-2025-004, in preparation

Rare charm

Search for resonance-enhanced CP and angular asymmetries in $\Lambda_c^+ \to p\,\mu^+\mu^-$ decays

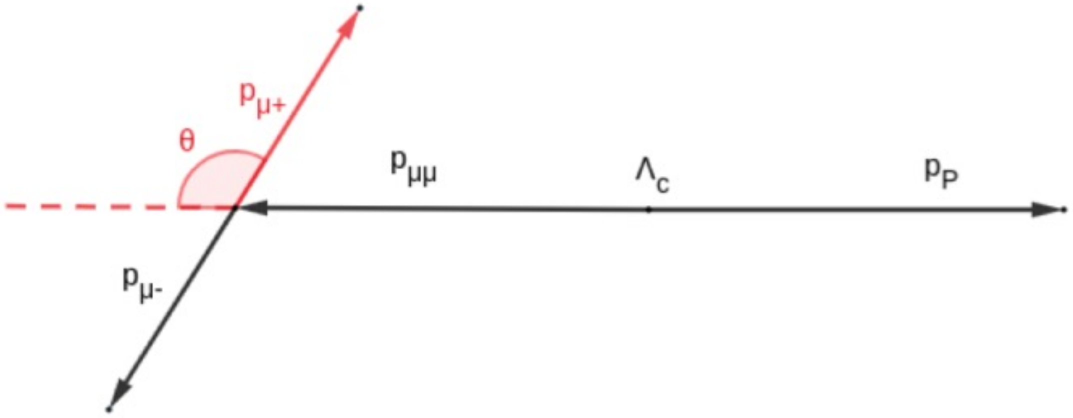
arXiv:2502.04013

Asymmetries in $\Lambda_c^+ \to p\,\mu^+\mu^-$ decays

- First study of angular and CP asymmetries in rare baryonic charm decays

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

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



arXiv:2502.04013

Asymmetries in $\Lambda_c^+ \to p\,\mu^+\mu^-$ decays

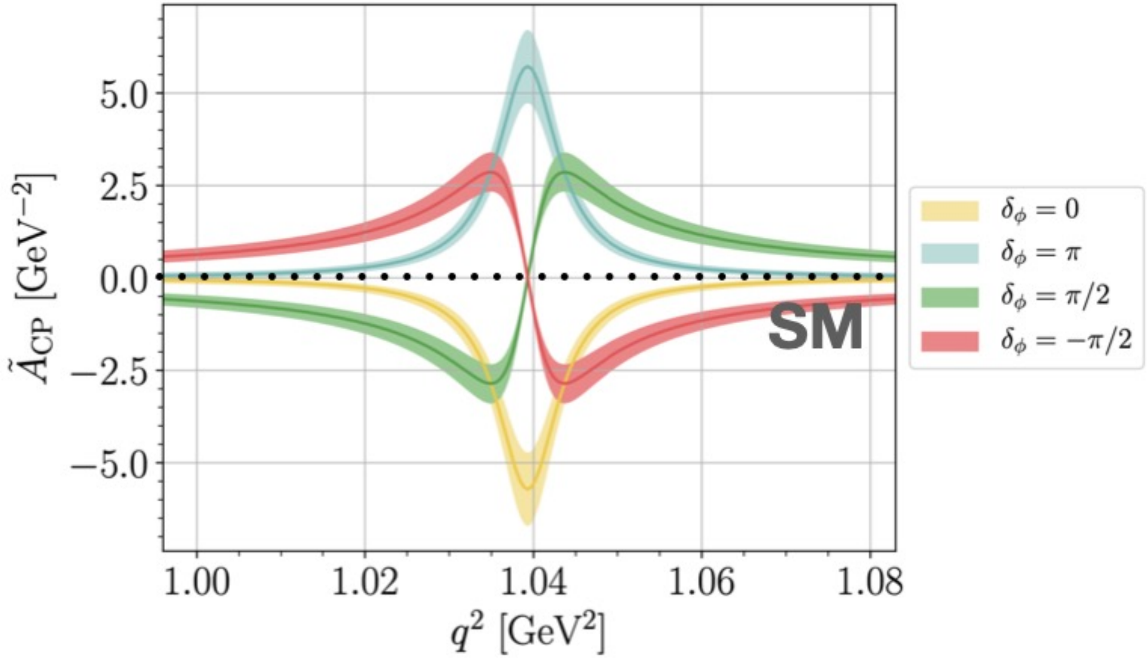
JHEP 09 (2021) 208

- First study of angular and CP asymmetries in rare baryonic charm decays

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

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

- Decays dominated by resonant contributions in φ region
- Looking for NP-SM interference in null tests



arXiv:2502.04013

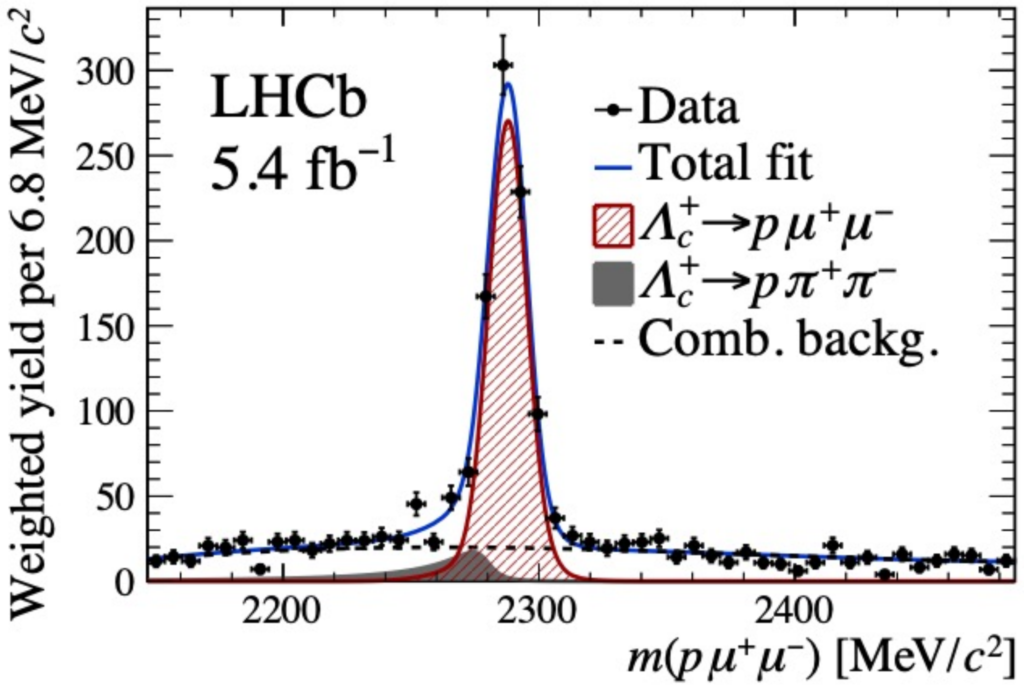
Asymmetries in $\Lambda_c^+ \to p\, \mu^+\mu^-$ decays

- First study of angular and CP asymmetries in rare baryonic charm decays

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

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

- Decays dominated by resonant contributions in φ region
- Looking for NP-SM interference in null tests
- Using 5.4 fb^{-1} in Run2 dataset



Signal yield ~ 800 events around φ resonance

arXiv:2502.04013

Asymmetries in $\Lambda_c^+ \to p\,\mu^+\mu^-$ decays

- Measuring A_{FB} separate for charge conjugates:

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

Results integrated in dimuon mass

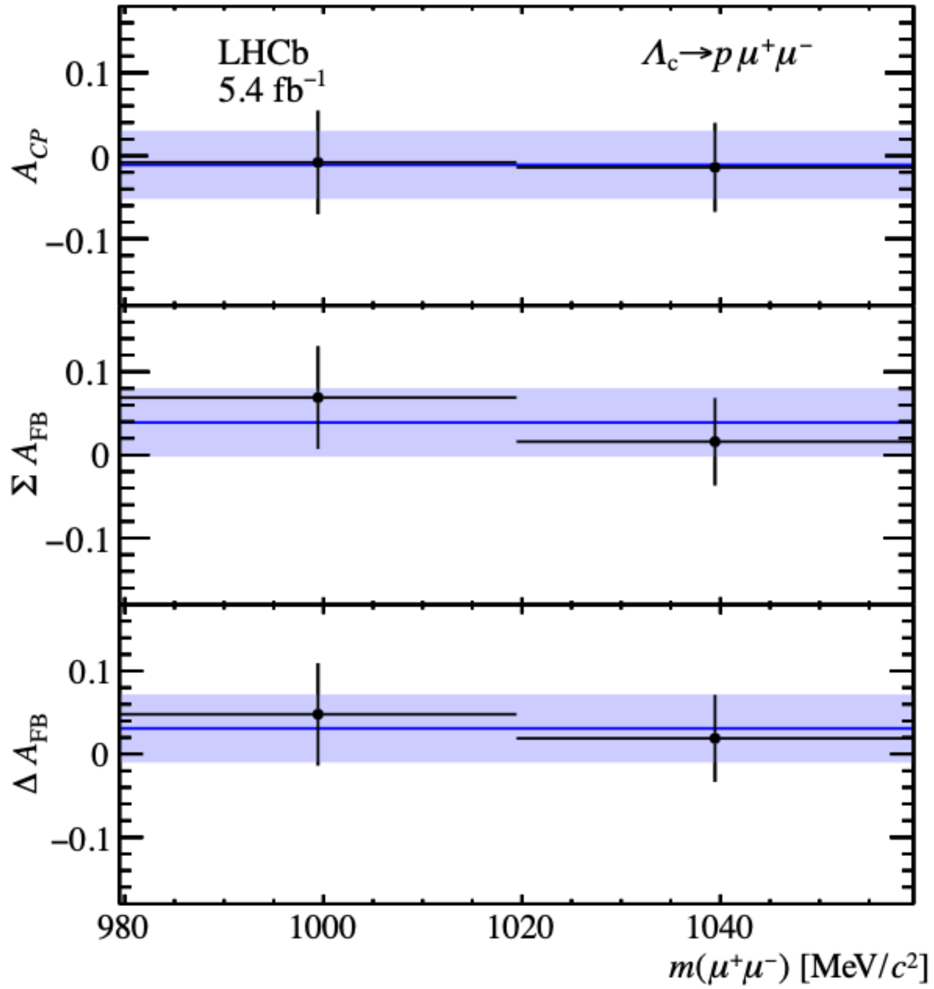
Stat. Sys.

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

No significant deviation from SM observed

Measurement competitive for setting constraints to BSM physics!

(Hiller et al.) arXiv 2410.00115



arXiv:2502.04013

Rare charm

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

arXiv:2412.09414

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

- First LHCb study on $D^0 \to h^+h^-e^+e^-$ rare charm decays ($h = \pi, K$)
  arXiv:2412.09414
- Experimental status:

	$D^0 \to \pi^+\pi^-e^+e^-$	$D^0 \to K^+K^-e^+e^-$	
BESIII	$< 7 \times 10^{-6}$	$< 1.1 \times 10^{-5}$	PRD 97, (2018) 072015
Belle	$< [3.1, 7.2] \times 10^{-7}$	$< [2.3, 7.7] \times 10^{-7}$	Moriond 2024 presentation

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

- First LHCb study on $D^0 \to h^+h^-e^+e^-$ rare charm decays ($h = \pi, K$)
  arXiv:2412.09414
- Experimental status:

	$D^0 \to \pi^+\pi^-e^+e^-$	$D^0 \to K^+K^-e^+e^-$
BESIII	$< 7 \times 10^{-6}$	$< 1.1 \times 10^{-5}$
Belle	$< [3.1, 7.2] \times 10^{-7}$	$< [2.3, 7.7] \times 10^{-7}$

PRD 97, (2018) 072015

Moriond 2024 presentation

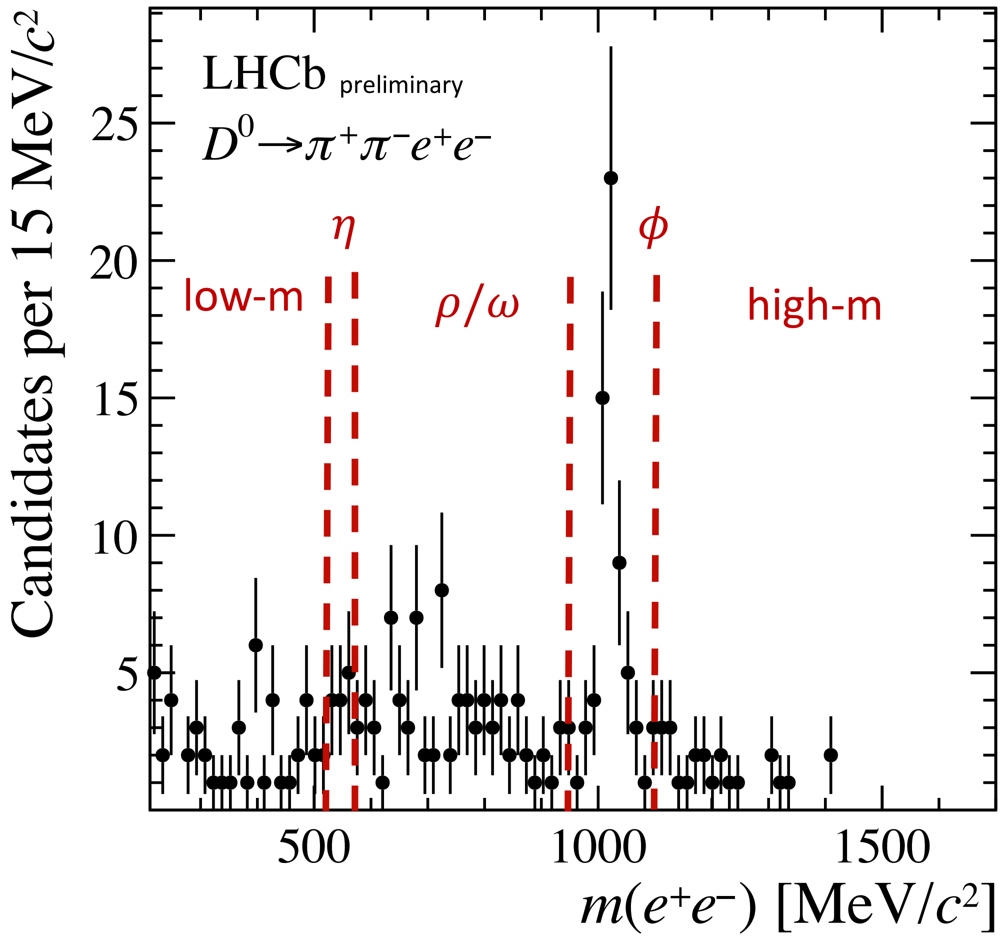
- Muon modes $D^0 \to h^+h^-\mu^+\mu^-$ already studied by LHCb with observation in both modes

Channel	Total $[\times 10^{-8}]$	low mass $[\times 10^{-8}]$	η $[\times 10^{-8}]$	ρ/ω $[\times 10^{-8}]$	ϕ $[\times 10^{-8}]$	high mass $[\times 10^{-8}]$
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	96.4 ± 12	7.8 ± 2.1	< 2.4 at 90 % CL	40.6 ± 5.7	45.4 ± 5.9	< 2.8 at 90 % CL
$D^0 \to K^+K^-\mu^+\mu^-$	15.4 ± 3.2	2.6 ± 1.3	< 0.7 at 90 % CL	12.0 ± 2.7		

PRL 119 (2017) 181805

Analysis strategy

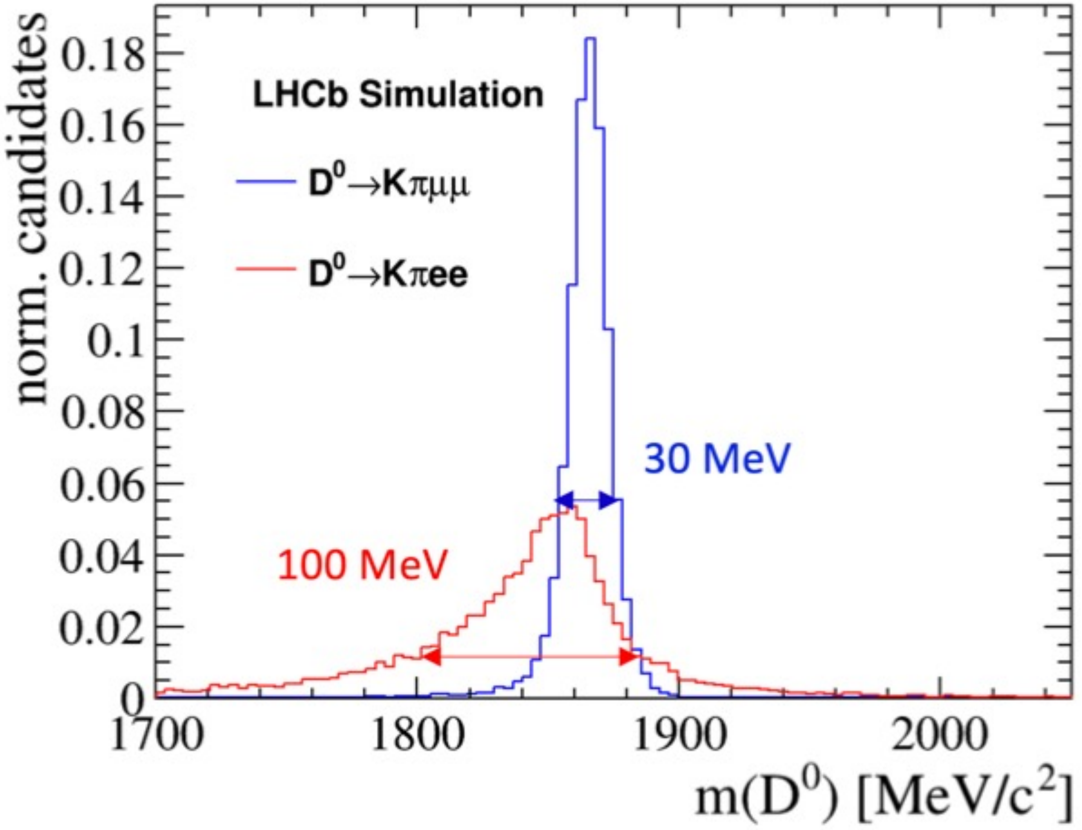
- Measurement integrated and in dilepton mass bins (same as muon mode analysis)



arXiv:2412.09414

Analysis strategy

- Measurement integrated and in dilepton mass bins (same as muon mode analysis)
- Challenges with electrons:
  - Lower trigger efficiency
  - Poorer mass resolution due to bremsstrahlung
- Split dataset in bremsstrahlung categories to control different types of backgrounds

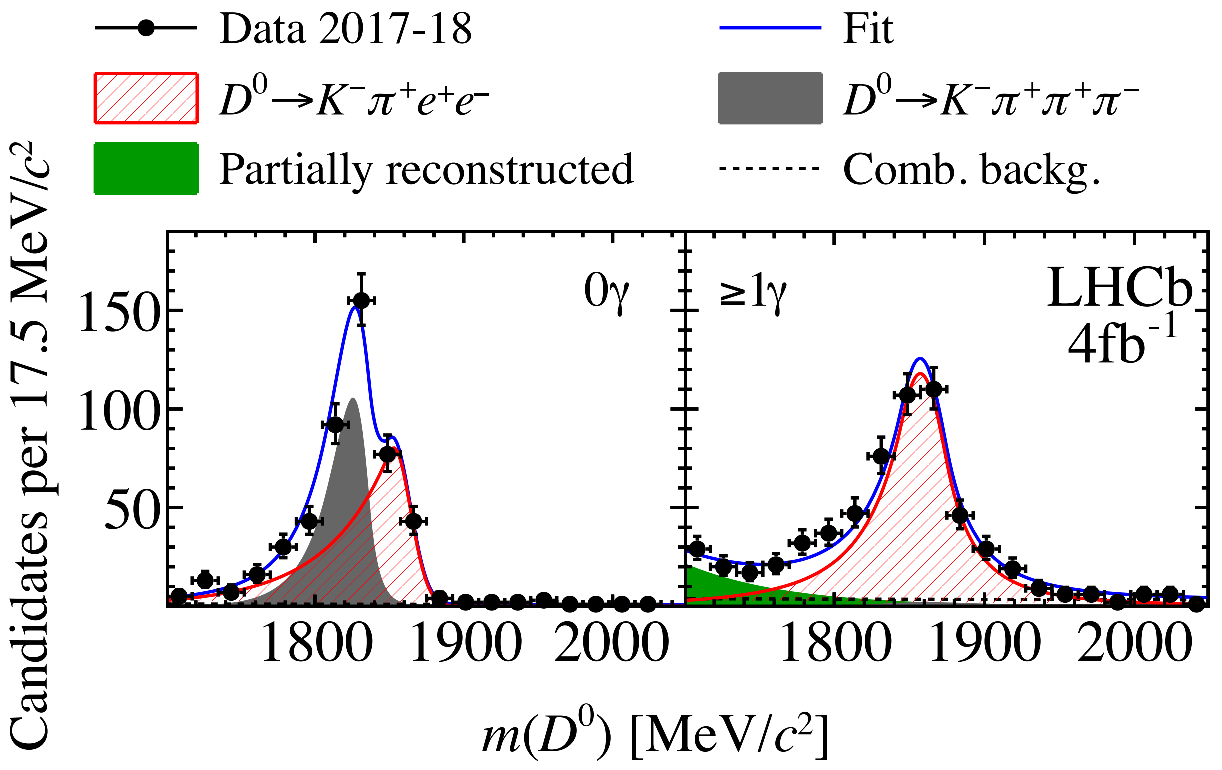


A. Scarabotto, PhD thesis, 04323454 (2023)

arXiv:2412.09414

Analysis strategy

- Measurement integrated and in dilepton mass bins (same as muon mode analysis)
- Challenges with electrons:
  - Lower trigger efficiency
  - Poorer mass resolution due to bremsstrahlung
- Split dataset in bremsstrahlung categories to control different types of backgrounds
- Using $D^0 \to K^- \pi^+ e^+ e^-$ as normalization channel



$$N_{D^0 \to K^- \pi^+ e^+ e^-} = 820 \pm 39$$

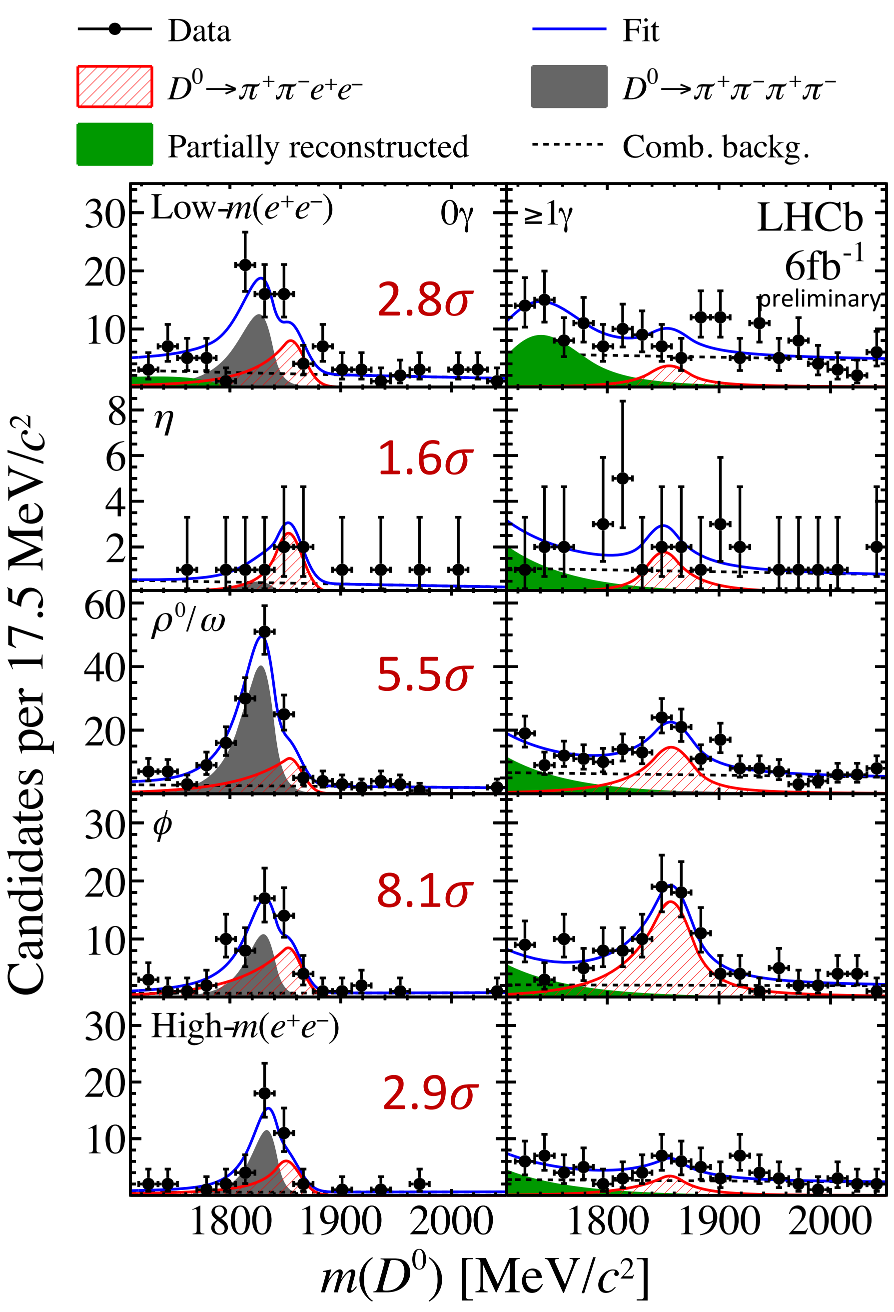
in ρ/ω dilepton mass region

arXiv:2412.09414

$D^0 \to \pi^+\pi^-e^+e^-$

	$D^0 \to \pi^+\pi^-e^+e^-$	
$m(e^+e^-)$ region	$[\mathrm{MeV}/c^2]$	$\mathcal{B}\ [10^{-7}]$
Low mass	211–525	$< 4.81\,(5.39)$
η	525–565	$< 2.27\,(2.74)$
ρ^0/ω	565–950	$4.53 \pm 1.00 \pm 0.72 \pm 0.62$ *
ϕ	950–1100	$3.84 \pm 0.70 \pm 0.39 \pm 0.53$ *
High mass	> 1100	$< 2.00\,(2.17)$

First observation!



* Statistical, systematic and uncertainties related to norm. BF

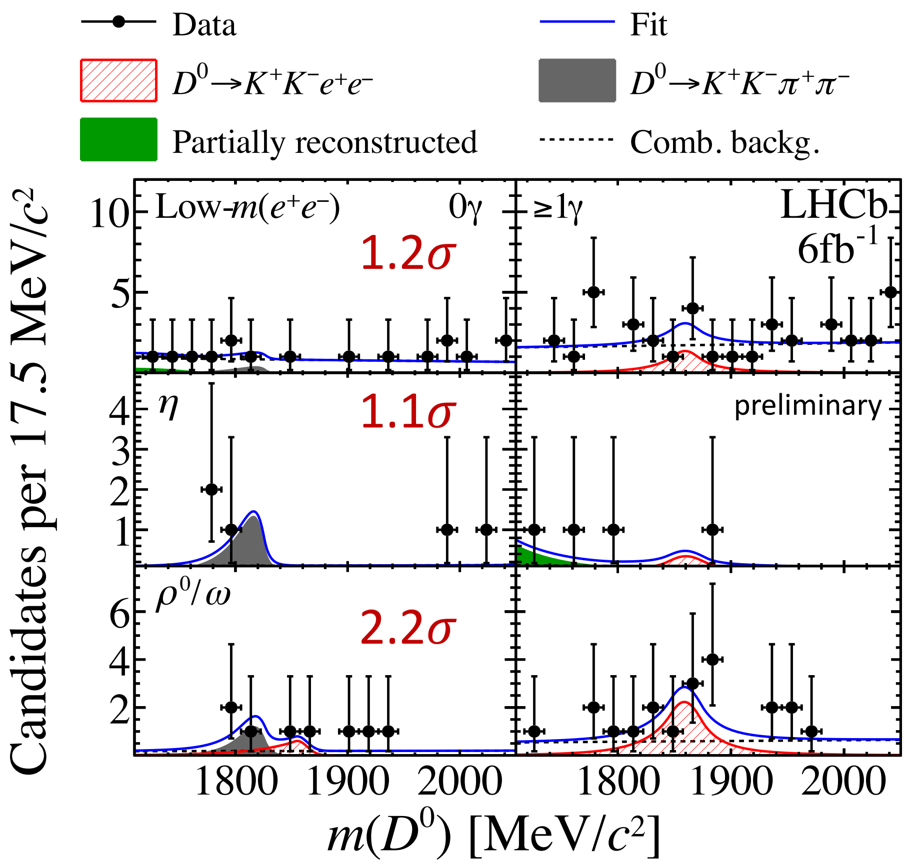
arXiv:2412.09414

$D^0 \to K^+K^-e^+e^-$

$D^0 \to \pi^+\pi^-e^+e^-$		
m(e^+e^-) region	[MeV/c^2]	$\mathcal{B}$ [10^{-7}]
Low mass	211–525	$< 4.81\,(5.39)$
η	525–565	$< 2.27\,(2.74)$
ρ^0/ω	565–950	$4.53 \pm 1.00 \pm 0.72 \pm 0.62$
ϕ	950–1100	$3.84 \pm 0.70 \pm 0.39 \pm 0.53$
High mass	> 1100	$< 2.00\,(2.17)$

$D^0 \to K^+K^-e^+e^-$		
m(e^+e^-) region	[MeV/c^2]	$\mathcal{B}$ [10^{-7}]
Low mass	211–525	$< 0.97\,(1.05)$
η	525–565	$< 0.44\,(0.54)$
ρ^0/ω	> 565	$< 2.15\,(2.47)$

World's best upper limits



arXiv:2412.09414

Comparison with muon modes

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

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

- Integrating over the dielectron mass ranges $D^0 \to \pi^+\pi^-e^+e^-$: compatible within 1.3σ with muon mode

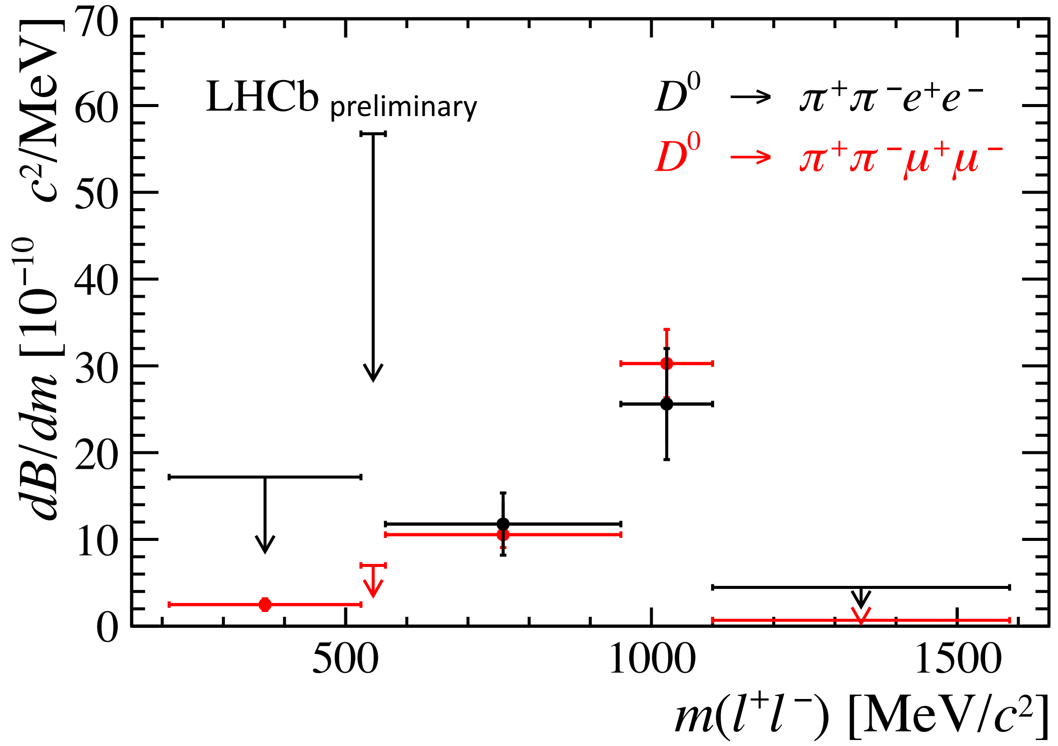
arXiv:2412.09414

Comparison with muon modes

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

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

- Integrating over the dielectron mass ranges $D^0 \to \pi^+\pi^-e^+e^-$: compatible within 1.3σ with muon mode
- Similarly in in ρ/ω and φ dilepton mass regions confirming lepton flavour universality at the current level of precision



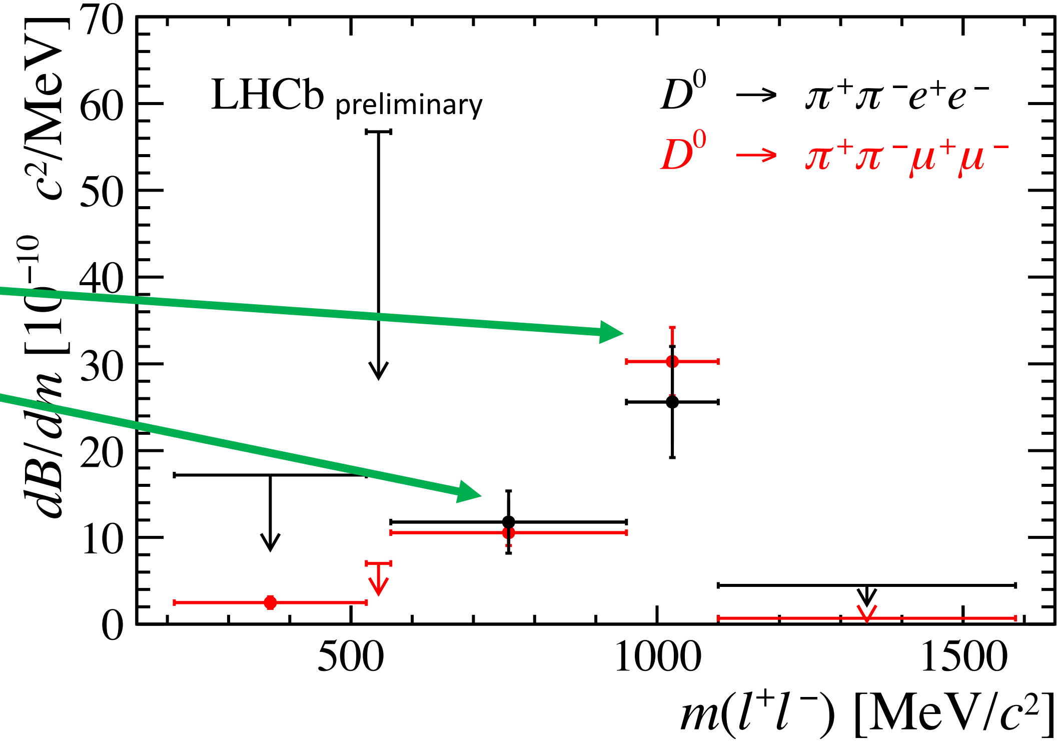
arXiv:2412.09414

Comparison with muon modes

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

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) \quad = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

- Integrating over the dielectron mass ranges $D^0 \to \pi^+\pi^-e^+e^-$: compatible within 1.3σ with muon mode
- Similarly in in ρ/ω and φ dilepton mass regions confirming lepton flavour universality at the current level of precision



arXiv:2412.09414

Conclusions

- Rare and very rare decays constitute a unique environment to look for New Physics, including beauty, charm and strange sectors
- LHCb is giving a major contribution in the field:
  - $\Sigma^+ \to p\,\mu^+\mu^-$: first observation of rarest hyperon decay LHCb-CONF-2024-002
  - $B^0 \to K^{*0}\,\tau^\pm e^\mp$: most stringent limit in $b \to s\tau\ell$ so far LHCb-PAPER-2025-004, in preparation
  - $\Lambda_c^+ \to p\,\mu^+\mu^-$: CP and angular asymmetries measurement competitive to constrain NP models arXiv:2502.04013
  - $D^0 \to h^+h^-e^+e^-$: first observation in $D^0 \to \pi^+\pi^-e^+e^-$ and world's best upper limit in $D^0 \to h^+h^-e^+e^-$ decays arXiv:2412.09414
- Prospects: exploit the larger Run3 dataset with improved efficiency from the fully software trigger to achieve unprecedented precision in these measurements

Backup

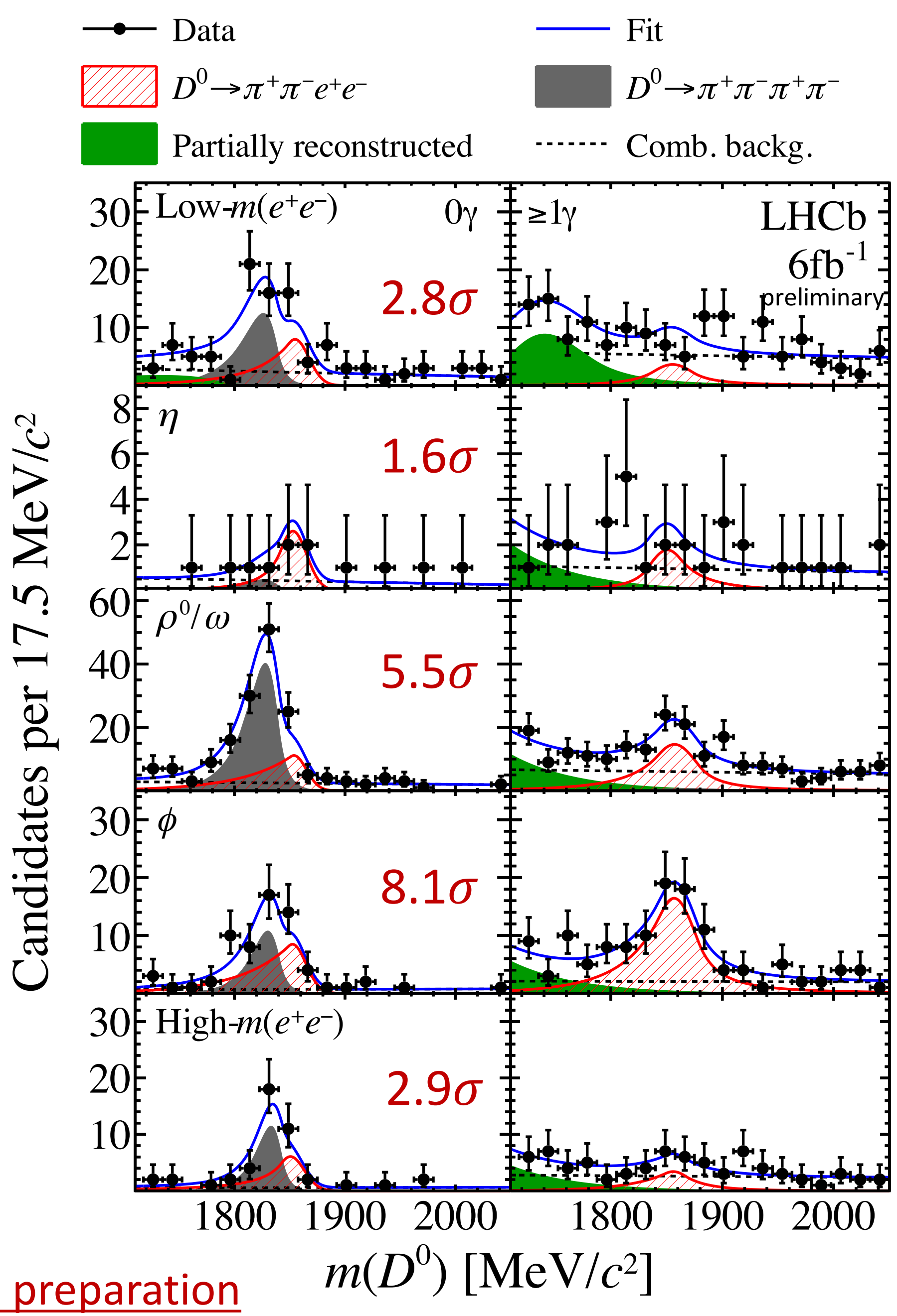
$D^0 \to \pi^+\pi^-e^+e^-$

- First observation of $D^0 \to \pi^+\pi^-e^+e^-$ in ρ/ω and φ dilepton mass regions
- World's best upper limits in other regions

$D^0 \to \pi^+\pi^-e^+e^-$			
$m(e^+e^-)$ region	$[\mathrm{MeV}/c^2]$	$\mathcal{B}\ [10^{-7}]$	
Low mass	211–525	$< 4.81\ (5.39)$	
η	525–565	$< 2.27\ (2.74)$	
ρ^0/ω	565–950	$4.53 \pm 1.00 \pm 0.72 \pm 0.62$	*
ϕ	950–1100	$3.84 \pm 0.70 \pm 0.39 \pm 0.53$	*
High mass	> 1100	$< 2.00\ (2.17)$	

First observation!

* Statistical, systematic and uncertainties related to norm. BF

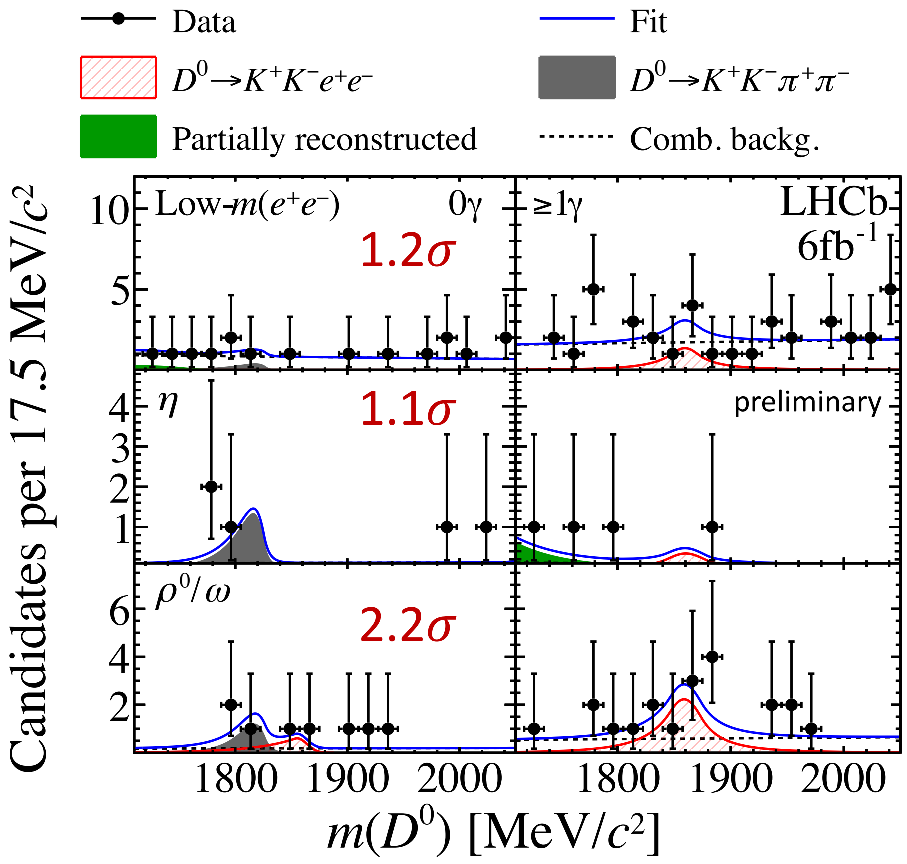


LHCb-PAPER-2024-047, in preparation

$D^0 \to K^+K^-e^+e^-$

- No evidence with current precision
- World's best upper limits reported in all dilepton mass bins

$m(e^+e^-)$ region	$D^0 \to K^+K^-e^+e^-$ [MeV/c^2]	$\mathcal{B}$ [10^{-7}]
Low mass	211–525	$< 0.97\,(1.05)$
η	525–565	$< 0.44\,(0.54)$
ρ^0/ω	> 565	$< 2.15\,(2.47)$

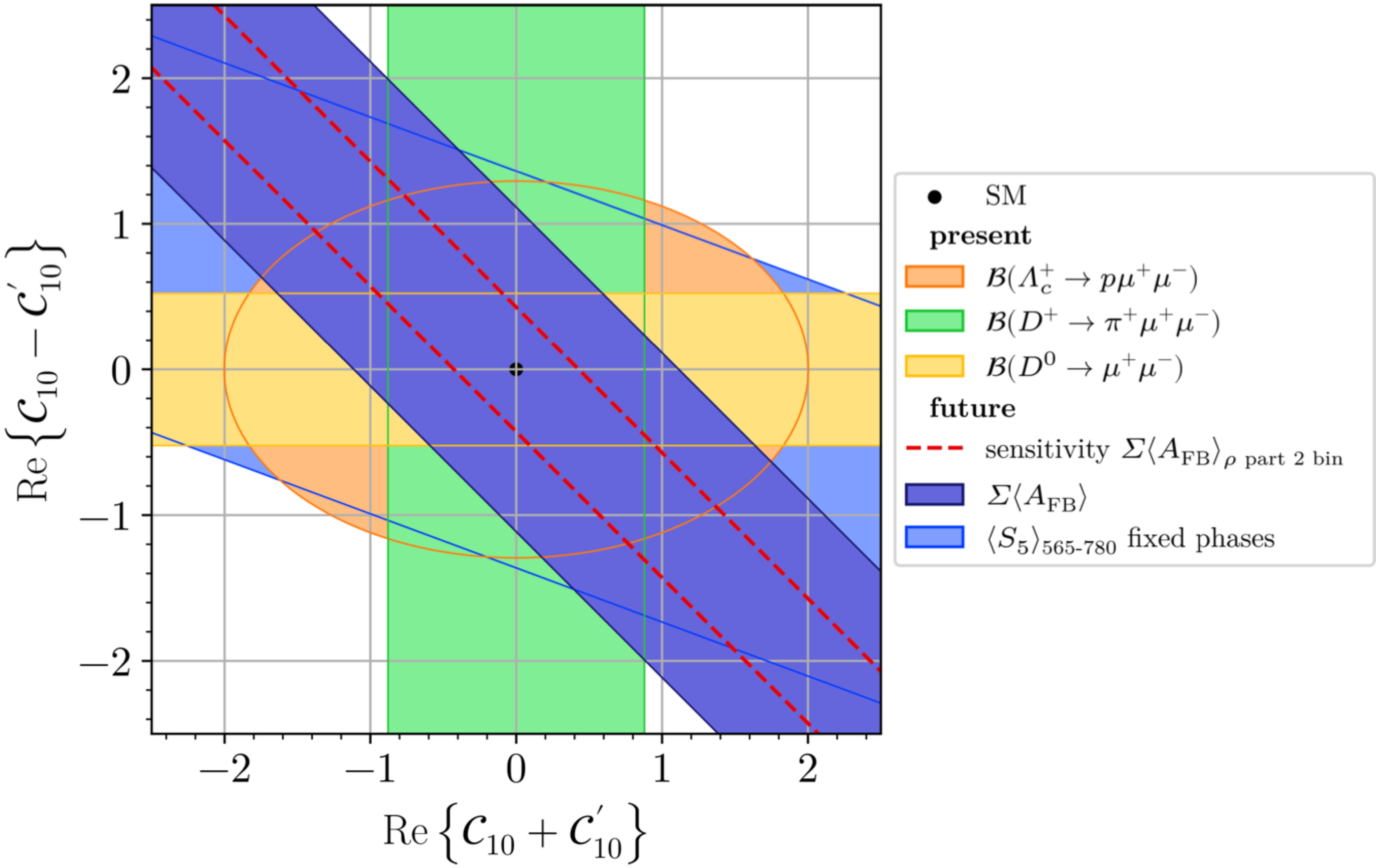


LHCb-PAPER-2024-047, in preparation

Rare charm observables combination

- From the theory side:
  - study trying to combine all accessible observables in rare charm decays

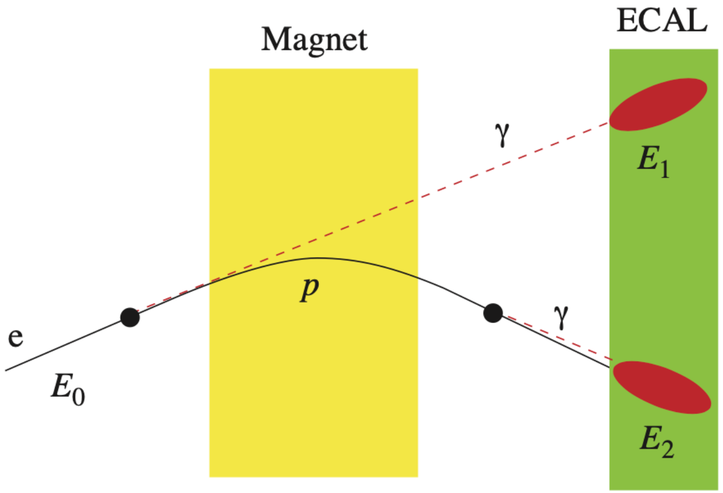
  arXiv 2410.00115

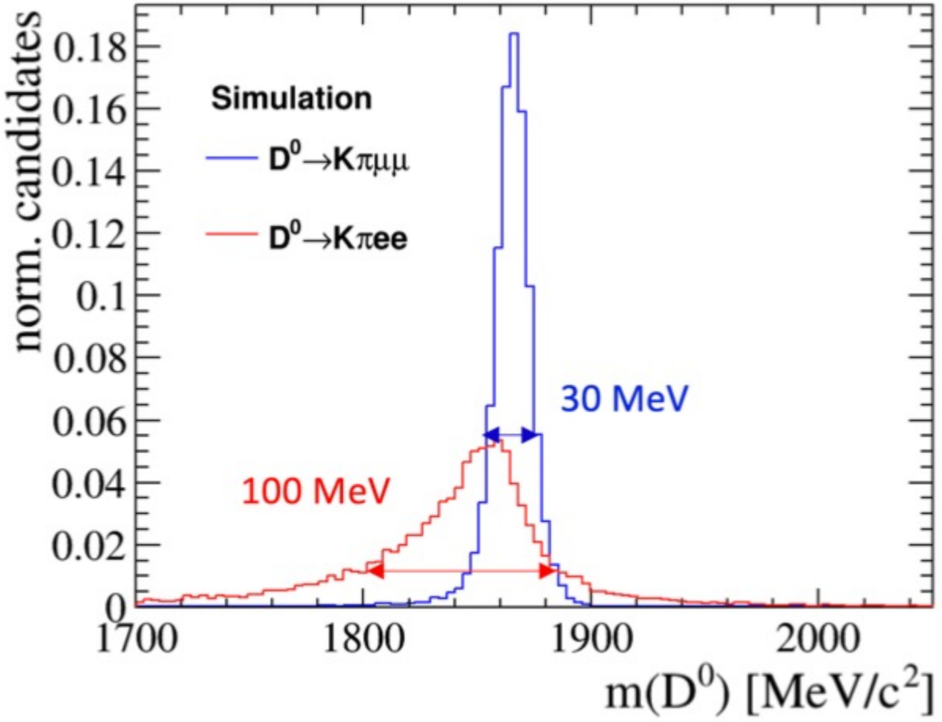


Electrons at LHCb

1. Lower trigger efficiency compared to muon modes: high occupancy in calorimeters
2. Bremsstrahlung effects: electrons-detector material interaction

- Candidates split in no-brem (0γ) and with-brem ($\geq 1\gamma$) categories to control different types of background





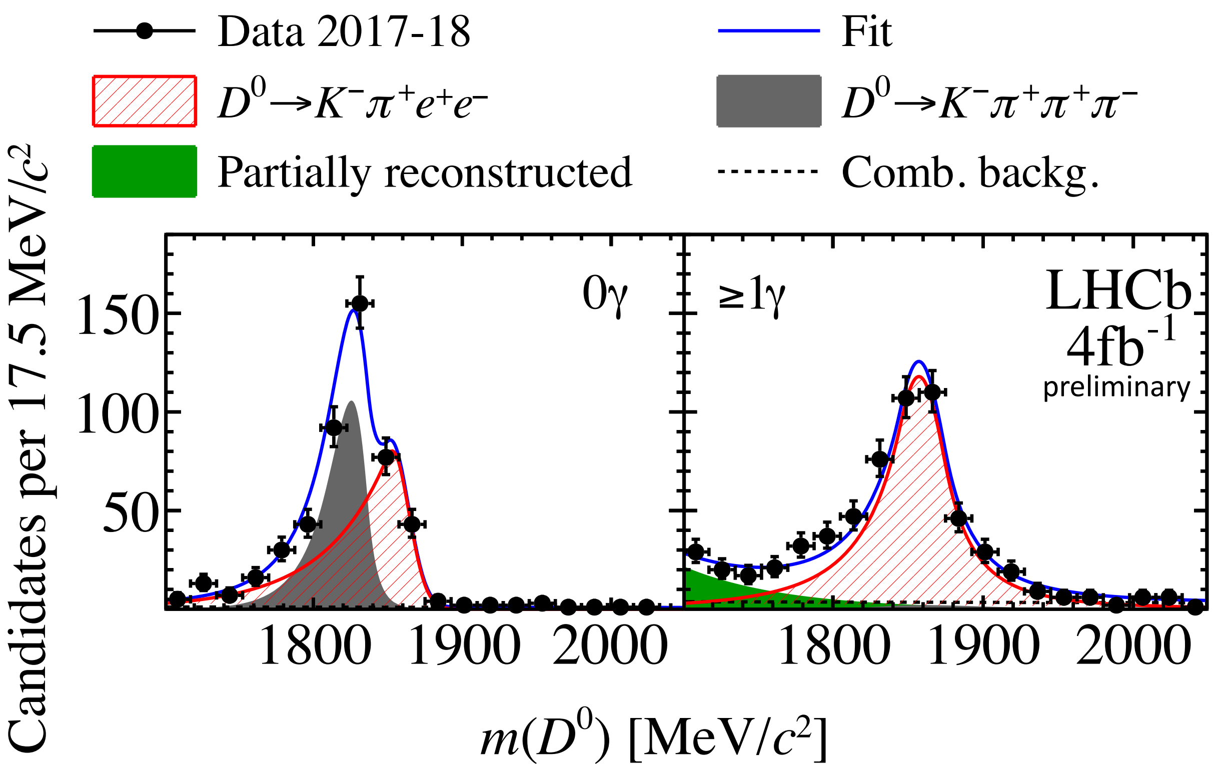
A. Scarabotto, PhD thesis, 04323454 (2023)

LHCb-PAPER-2024-047, in preparation

Background studies and $D^0 \to K^-\pi^+e^+e^-$ fit

- Main backgrounds:
  - Combinatorial
  - $D^0 \to K^-\pi^+\pi^+\pi^-$ with pions mis-id as electrons
  - Partially reconstructed: more prominent in with-brem category with wrongly attached photons

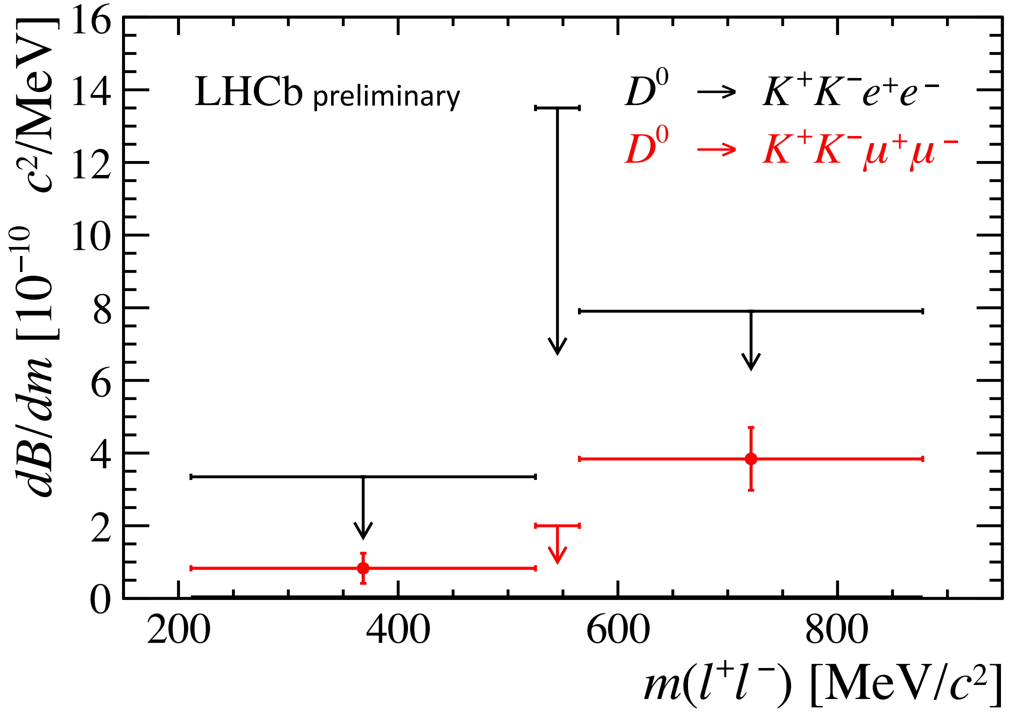
$N_{D^0\to K^-\pi^+e^+e^-} = 820 \pm 39$
in ρ/ω dilepton mass region

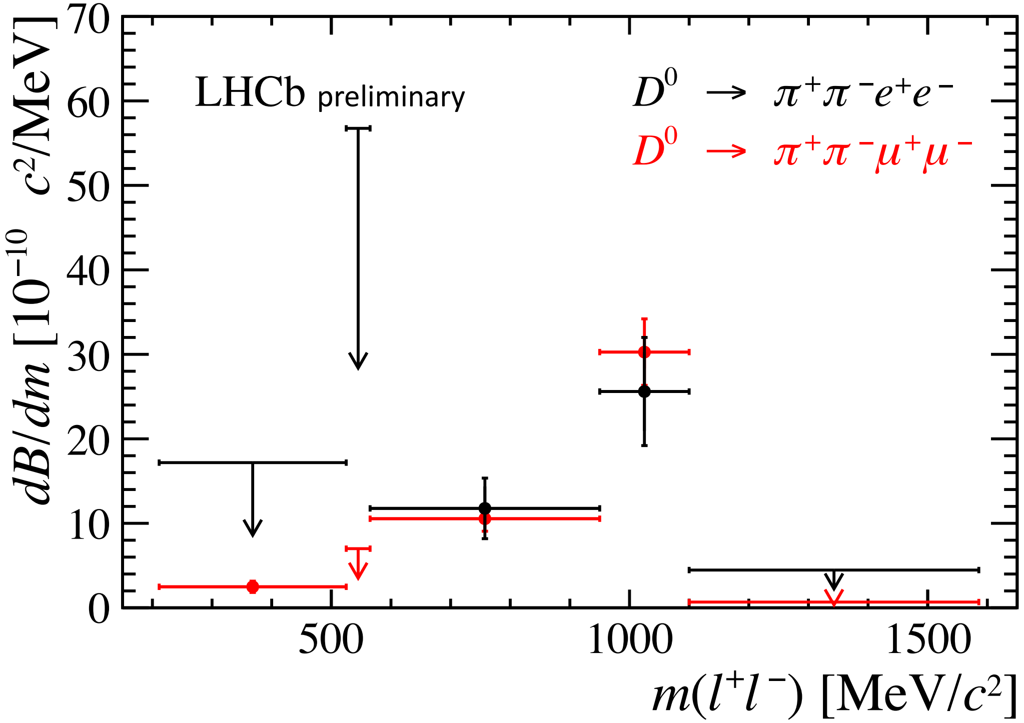


LHCb-PAPER-2024-047, in preparation

Comparison with muon modes

- Results compatible with muonic modes confirming lepton universality at the current level of precision ($D^0 \to \pi^+\pi^-e^+e^-$ in ρ/ω and φ dilepton mass regions)
- Less stringent upper limits in all other dilepton mass regions compared to muon modes





LHCb-PAPER-2024-047, in preparation

$D^0 \to \pi^+\pi^-e^+e^-$ correlations

- Integrating over the dielectron mass ranges considered for $D^0 \to \pi^+\pi^-e^+e^-$ decays and accounting for correlations:

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

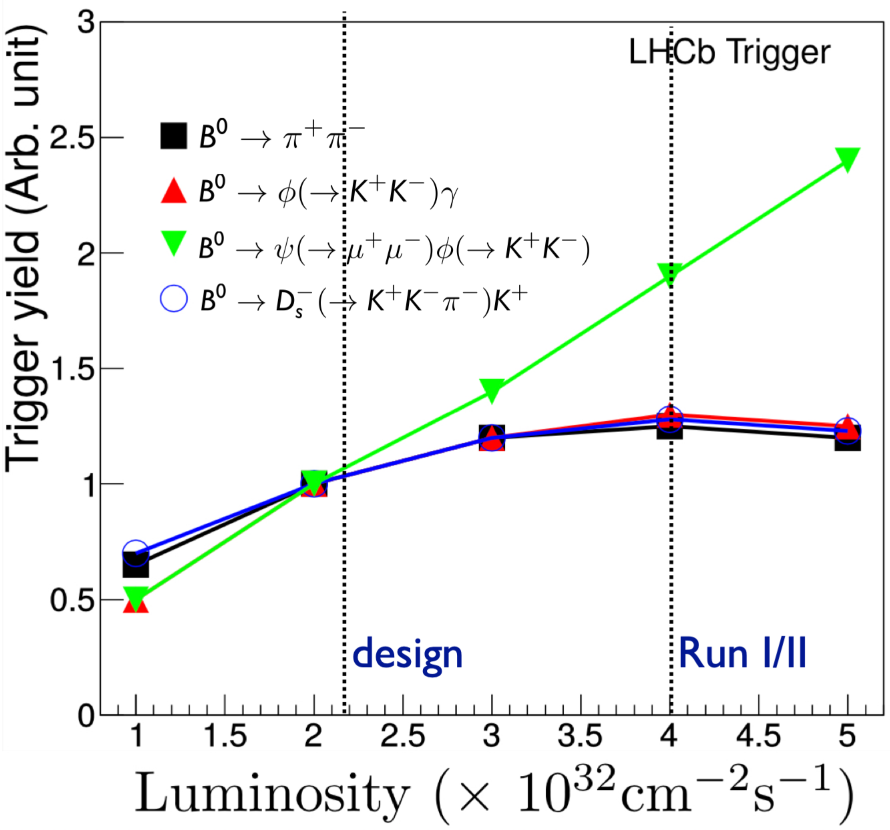
where uncertainties are statistical, systematic and due to normalization BF

$D^0 \to \pi^+\pi^-e^+e^-$		
$m(e^+e^-)$ region	[MeV/c^2]	$\mathcal{B}$ [10^{-7}]
Low mass	211–525	$2.81^{+1.00}_{-0.90} \pm 0.43 \pm 0.38$
η	525–565	$1.03^{+0.70}_{-0.50} \pm 0.21 \pm 0.14$
ρ^0/ω	565–950	$4.53 \pm 1.00 \pm 0.72 \pm 0.62$
ϕ	950–1100	$3.84 \pm 0.70 \pm 0.39 \pm 0.53$
High mass	> 1100	$1.05 \pm 0.40 \pm 0.18 \pm 0.14$

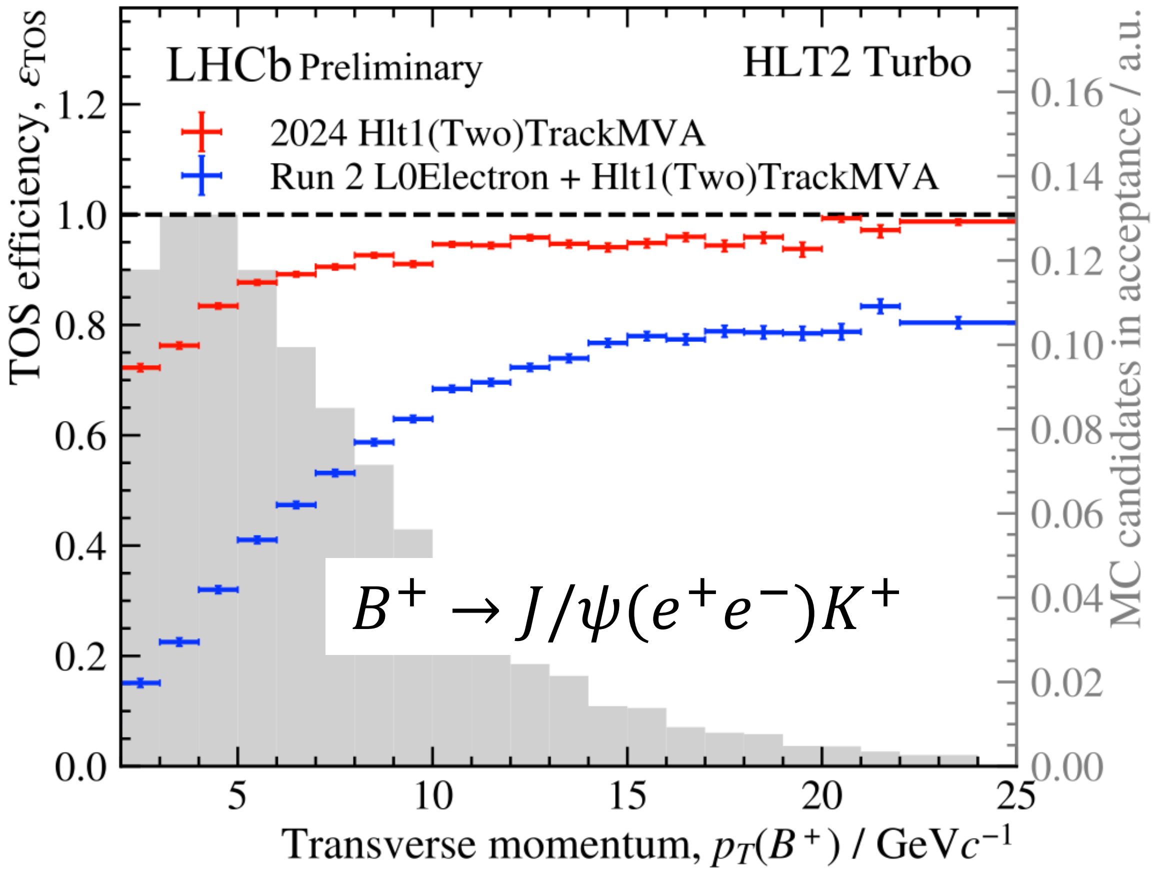
Table S3: Correlation coefficients related to the statistical and systematic uncertainties of the branching fractions of $D^0 \to \pi^+\pi^-e^+e^-$ decays in different dilepton mass regions. The matrix reported does not include uncertainties related the normalization mode branching fraction.

$D^0 \to \pi^+\pi^-e^+e^-$					
[MeV/c^2]	211-525	525-565	565-950	950-1100	>1100
211-525	1.00	0.07	0.20	0.17	0.12
525-565		1.00	0.18	0.16	0.11
565-950			1.00	0.37	0.26
950-1100				1.00	0.23
>1100					1.00

Electron trigger efficiency improvements in Run3



J. Phys.: Conf. Ser. **878** 012012



LHCB-FIGURE-2024-030

LFU in charm

Phys. Rev. D 98, 035041 (2018)

While data on muons [17] and electrons [18] exist for $D^0 \to \pi^+\pi^- l^+ l^-$ and $D^0 \to K^+K^- l^+ l^-$ decays, see table I, unfortunately, this does not permit to compute the respective clean LNU-ratios (40) due to incompatible q^2-cuts employed by the two experiments. In particular, BESIII included q^2-regions not accessible with dimuons and vetoed the $\phi \to e^+e^-$ region. We recommend to give dielectron results for q^2 values above the dimuon threshold to allow for a measurement of $R^D_{P_1 P_2}$

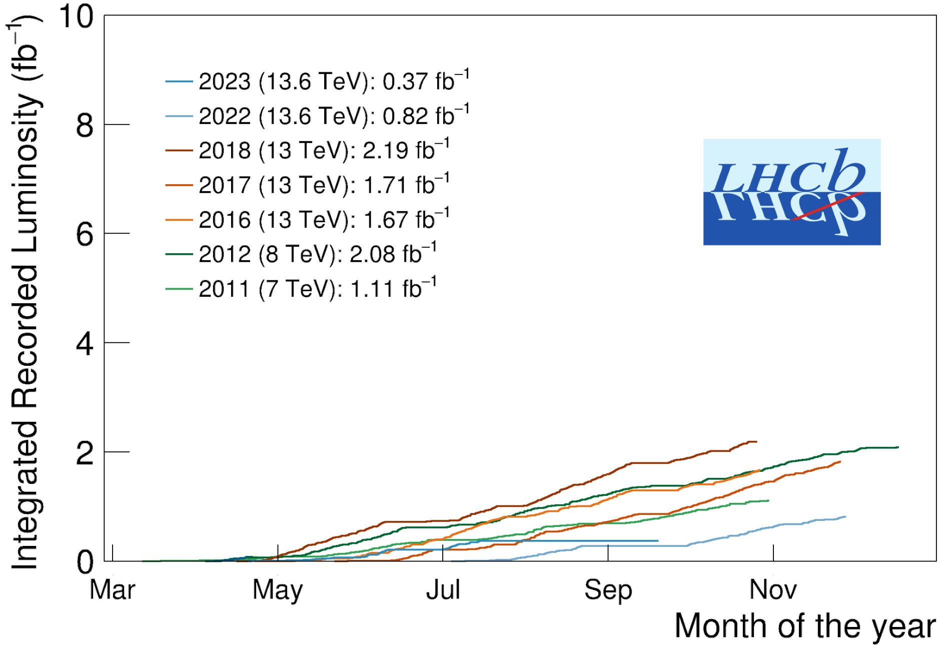
$$R^D_{P_1 P_2} = \frac{\int_{q^2_{\min}}^{q^2_{\max}} d\mathcal{B}/dq^2 (D \to P_1 P_2 \mu^+ \mu^-)}{\int_{q^2_{\min}}^{q^2_{\max}} d\mathcal{B}/dq^2 (D \to P_1 P_2 e^+ e^-)}$$ with same cuts $q^2_{\text{min}} \geq 4m^2_\mu$

full q^2	SM	BSM	LQ	hi q^2 SM	LQs	lo q^2 SM	BSM
$R^D_{\pi\pi}$	$1.00 \pm \mathcal{O}(\%)$	0.85 ...0.99	SM-like	$1.00 \pm \mathcal{O}(\%)$	0.7 ...4.4		
R^D_{KK}	$1.00 \pm \mathcal{O}(\%)$	SM-like	SM-like	NA	NA	$0.83 \pm \mathcal{O}(\%)$	0.60..0.87

Gudrun's talk at IW 2018

Prospects

- LHCb will continue to exploit the Run2 dataset:
  - $\Sigma^+ \to p\,\mu^+\mu^-$ integrated BF, CPV and angular asymmetries
  - Search for $K^0_S \to \pi^+\pi^-\mu^+\mu^-$ decays
  - $\Lambda_c^+ \to p\,\mu^+\mu^-$ and $D^+_{(s)} \to \pi^+\mu^+\mu^-$ CPV and angular analysis
  - Lepton flavour violating decays
  - Radiative decays
  - …



Prospects

- But … more than $9\ \mathrm{fb}^{-1}$ collected in Run3 just with 2024 data-taking year
- Exploit the improved trigger efficiency and our knowledge on rare decays to improve data analysis methods
- Plans for Run3:
  - $\Sigma^{+} \to \mathrm{p}\ \mu^{+}\mu^{-}$ CPV and angular analysis
  - $D^{0} \to h^{+}h^{-}\ell^{+}\ell^{-}$ LFU test
  - $D^{0} \to \mu^{+}\mu^{-}$ update
  - …