

# Experimental Activities Charm Flavour @TUDO

color  
meets  
flavor

1.27 GeV/c<sup>2</sup>  
 $\frac{2}{3}$   
 $\frac{1}{2}$  **C**  
charm

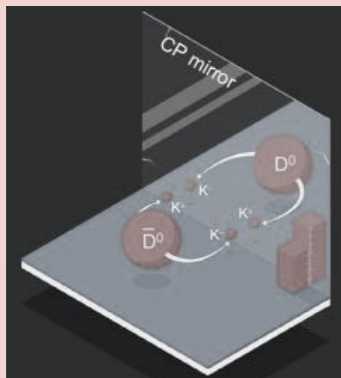
Search for new phenomena in  
strong and weak interactions

RA2 kick-off meeting  
Bonn October 25

# Charm Physics in CMF

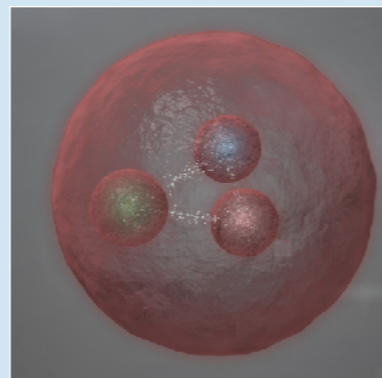
## Mixing and CPV

- Meson oscillations
- CPV two body
- CPV multi body
- ...



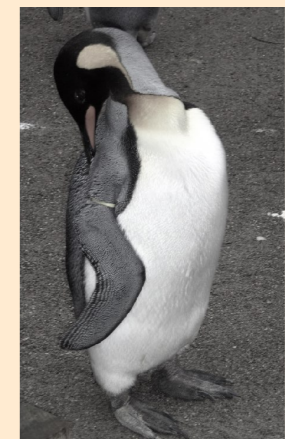
## Production and decay properties

- Charm lifetimes
- Hadronic structures and strong phases
- ...



## Rare decays

- Rare dilepton modes
- CPV and angular analyses
- Global interpretations
- ...

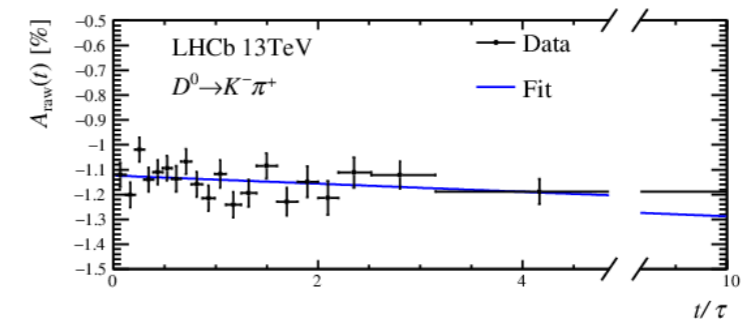


# What are the highlights of the past?

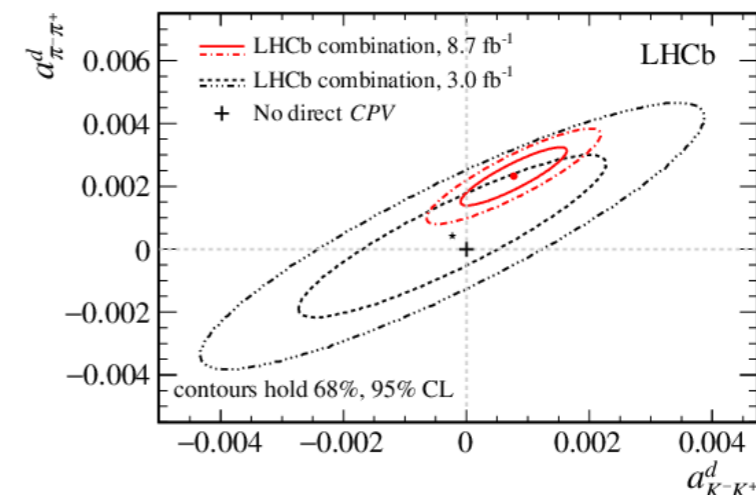
## Mixing and CPV

- Time-dependent CPV in  $D^0 \rightarrow hh$ 
  - Current precision  $\sim 10^{-4}$ , not our focus at the moment unless strong wish to improve in the cluster with current methods or develop new ones
- Direct CPV in  $D^0 \rightarrow hh$ : currently  $\sim 4\sigma$  evidence in pion mode
  - SM or not? Highly debated! SM computation extremely challenging due to hadronic effects  
Related theory work in CMF

Alex L., Aleksey, Maria Laura, *JHEP* 03 (2024) 151



[Phys. Rev. D101 \(2020\) 012005](#)



[Phys. Rev. Lett. 131 \(2023\) 091802](#)

# What are the highlights of the past?

## Rare decays

- Differential Branching fractions (at ~10%), angular analysis and CPV in  $D^0 \rightarrow K^+K^-\mu^+\mu^-$  and  $D^0 \rightarrow \pi^+\pi^-\mu^+\mu^-$  (at 2%)

- Charm version of  $B \rightarrow K^* \mu\mu$ , but very complicated hadronic system

- Promising avenue in charm: **null test measurements** but interpretation relies on knowledge of hadronic system

- Related theory work in CMF

Gudrun et al. Phys. Rev. D 98 (2018) 035041

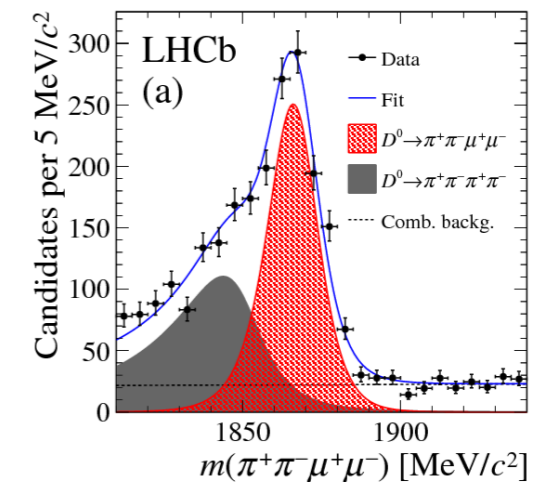
- Angular and CP asymmetries in  $\Lambda_c \rightarrow p\mu^+\mu^-$  (at 4%)

- Less precise, but simpler hadronic system (3-bodies), good NP sensitivity to some operators, potential to be leading for  $C_{10}$

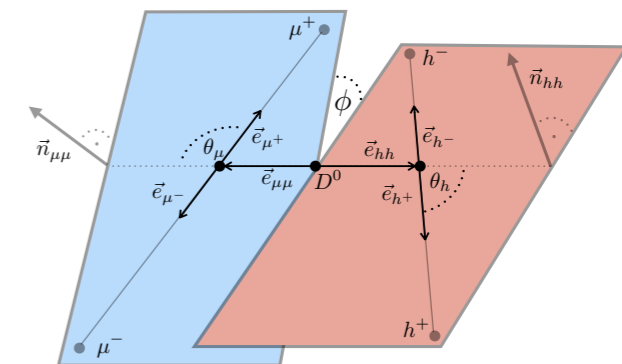
- Related theory work in CMF

Gudrun et al. Phys. Eur. Phys. J. C 82 (2022) 357

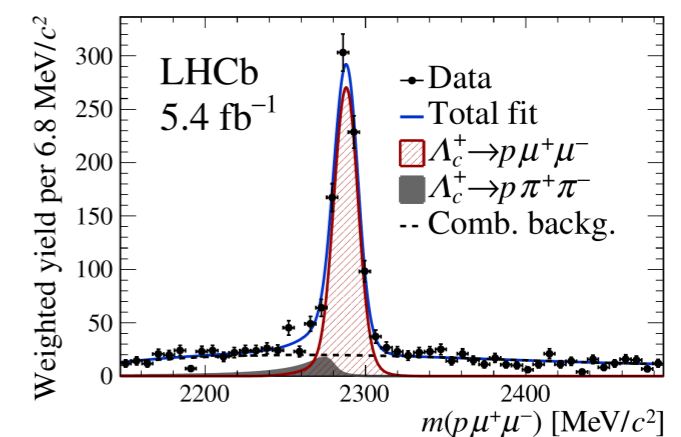
Phys. Rev. Lett. 121 (2018) 091801



Phys. Rev. Lett. 119 (2017) 181805



Phys. Rev. Lett. 128 (2022) 221801

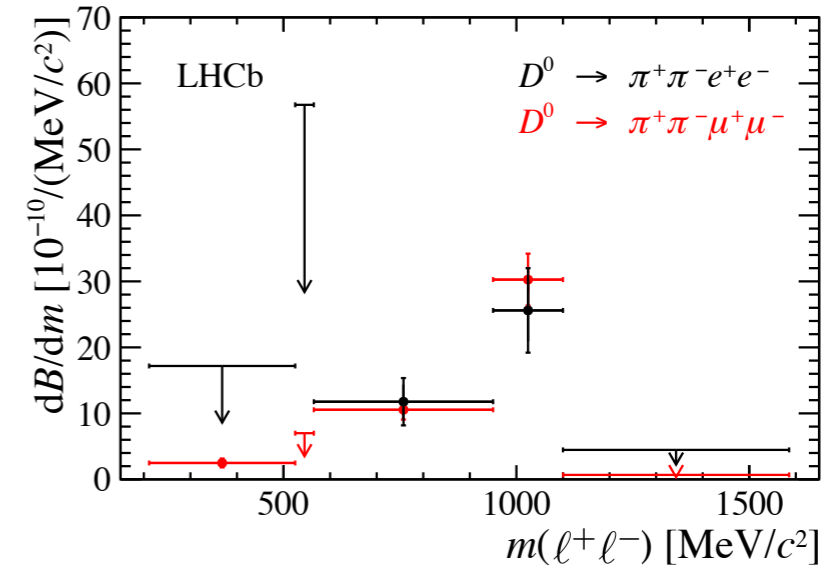


Phys. Rev. D111 (2025), L091101

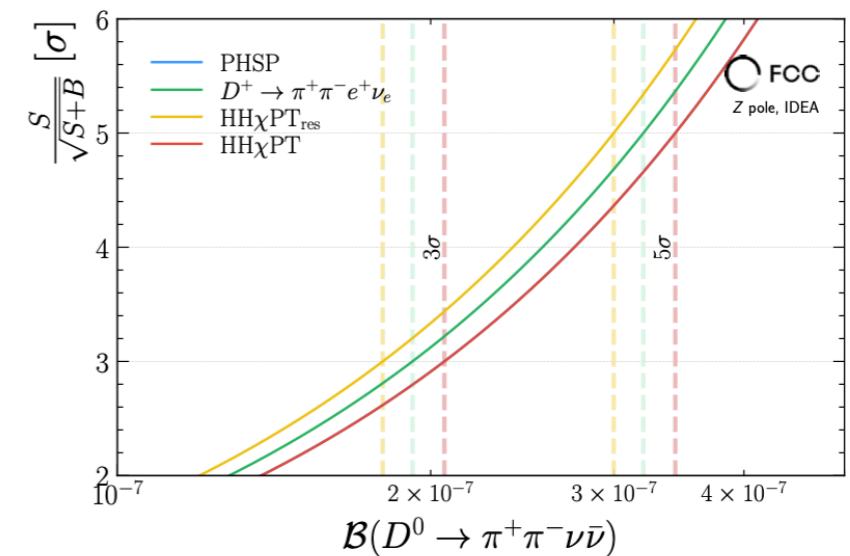
# What are the highlights of the past?

## Rare decays

- First observation electron modes and naive **LFU test**
  - Currently now our main focus for the near future unless strong interest. Is there?
- Charm at future facilities, example on the right  $D^0 \rightarrow \pi\pi\nu\nu$  at FCC, together with Gudrun and Dominik S.
  - Side remark: Many opportunities there yet unexplored. **Small side projects** possible for interested people, main experimental player in CMF is Belle II for dineutrino modes



[Phys. Rev. D111 \(2025\), L091101](#)



[arXiv:2509.10447](#)

# We are we doing now?

- Mostly exploring Run3, focussing on flagship measurements

- Start to work on update  $A_{CP}(hh)$  with Run3 (Luca B. And Serena → will move to CERN): Can we confirm large signal in  $D^0 \rightarrow \pi^+ \pi^-$ ?

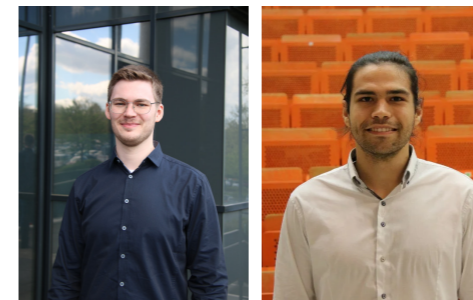
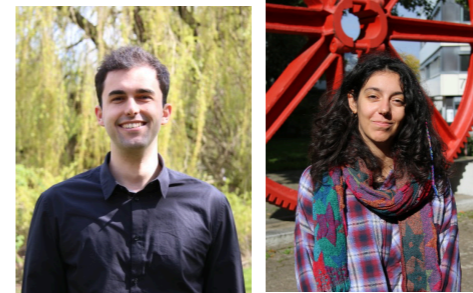
- Asymmetries in  $D^+ \rightarrow \pi^+ \mu^+ \mu^-$  Run2 (Luca T.) and  $D^+ \rightarrow \pi^+ \mu^+ \mu^-$  and Run3 (Christopher B.)

Related theory work in CMF:

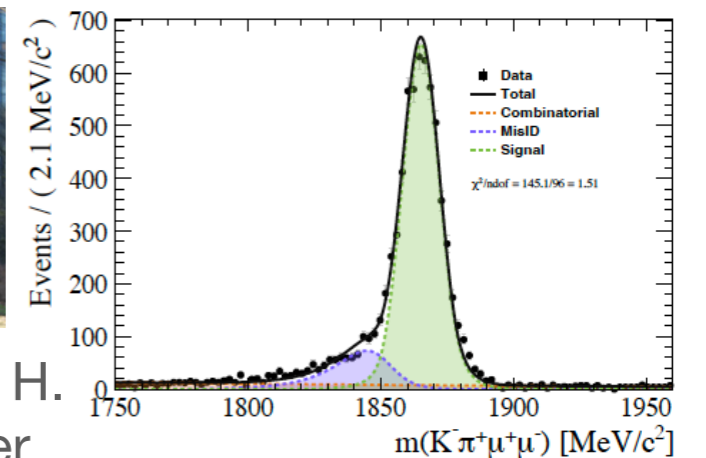
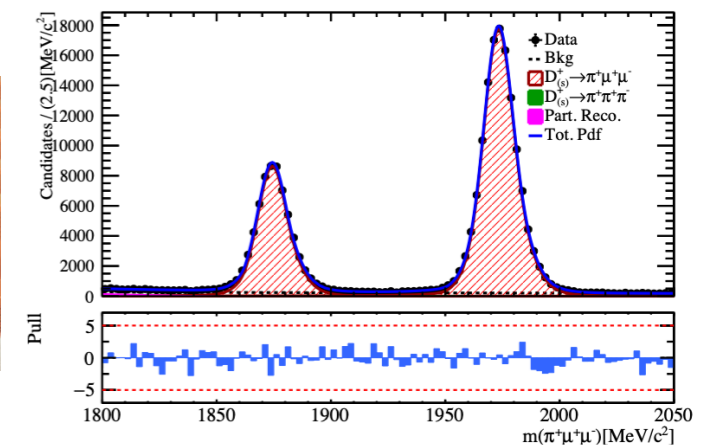
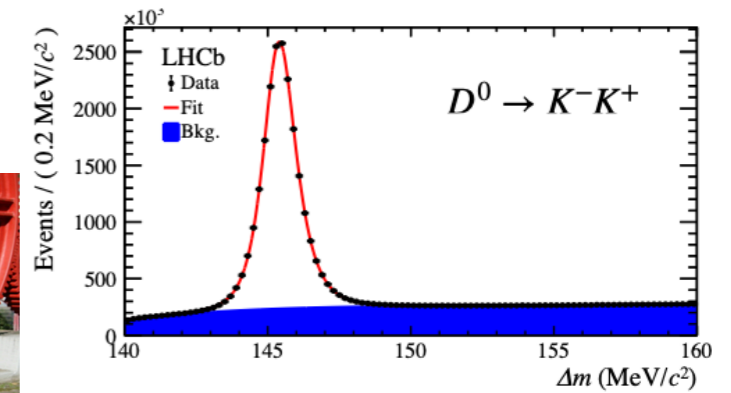
Anshika, Alex, Thomas, *JHEP* 08 (2025) 026  
 Gudrun et al *Eur.Phys.J.C* 80 (2020)

- Implemented  $D^0 \rightarrow K_s \mu^+ \mu^-$  in trigger after discussion with Thomas et al.

- First glimpse at four body modes  $D^0 \rightarrow h^+ h^- \mu^+ \mu^-$  and  $\Lambda_c \rightarrow p \mu^+ \mu^-$  with Run3 → huge yields. Uncertainties on asymmetries will be significantly reduced!



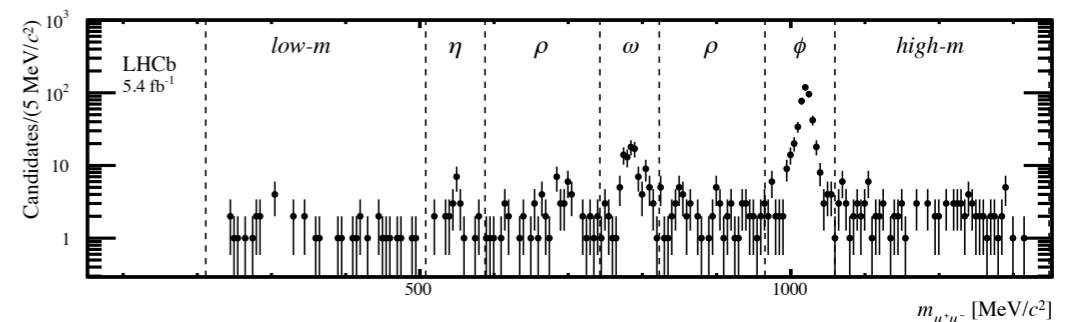
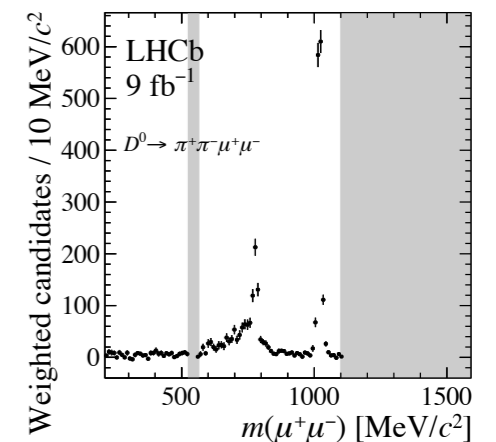
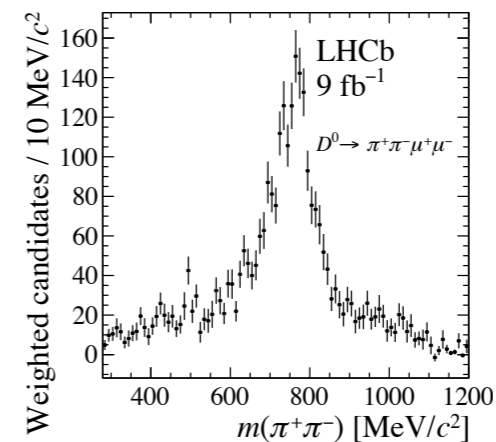
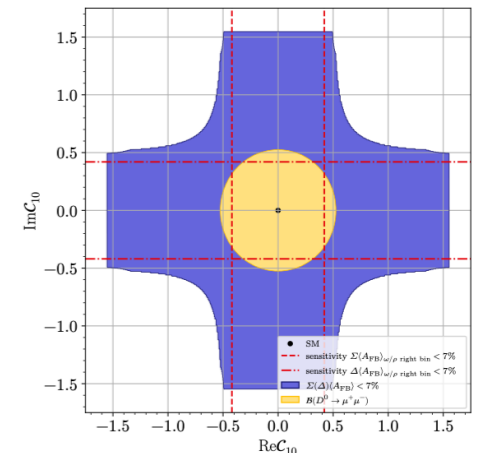
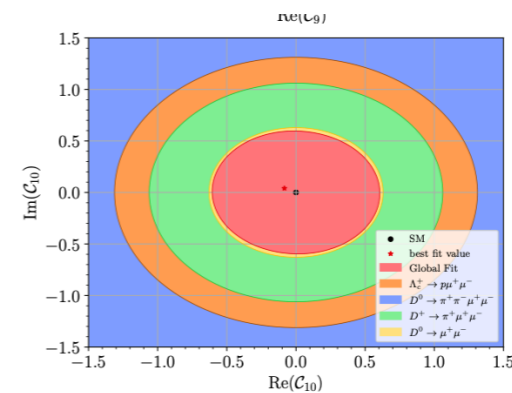
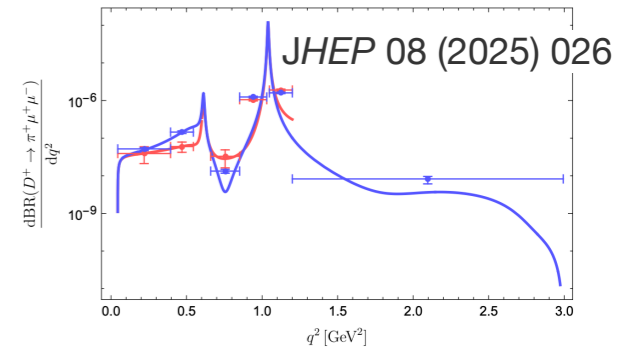
Master thesis H. Krämerkämper



Dataset	$N(D^0 \rightarrow K^- K^+ \mu^- \mu^+)$	$N(D^0 \rightarrow \pi^- \pi^+ \mu^- \mu^+)$
2.7 fb <sup>-1</sup> of 2024 data	834 ± 43	3701 ± 89
2.0 fb <sup>-1</sup> of 2012 data	34 ± 6	561 ± 28

# What do we want to do?

- Interpreting charm measurements and SM computations are a **stress test for non-perturbative QCD** models! What can we transport from B?
- First attempts for global fits using rare charm (Gudrun, *JHEP* 12 (2024) 102) show limitations: Hadronic composition of decays and relative strong phases: null test asymmetries  $\sim A_{SM} \cdot A_{NP}$
- Key questions we want to address in CMF:
  - How can we describe LD SM contributions?
  - How can we measure them? Which models do we use to fit the data? Need expertise:
    - **Differential BF/Amplitude fits  $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ ,  $\Lambda_c^+ \rightarrow p^+ \mu^+ \mu^-$**  ( $\rightarrow$  Model from Thomas et al?)
    - **Differential BF/Amplitude fits  $D^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-$**  (Expertise Christoph, Bastian, Sebastian?)
    - **Fit directly WC?** Requires model for SM and BSM amplitudes
- How can we publish the results in a way they are usable for others?  $\rightarrow$  connects to **IAL** (efficiency corrections, unfolding, ...)

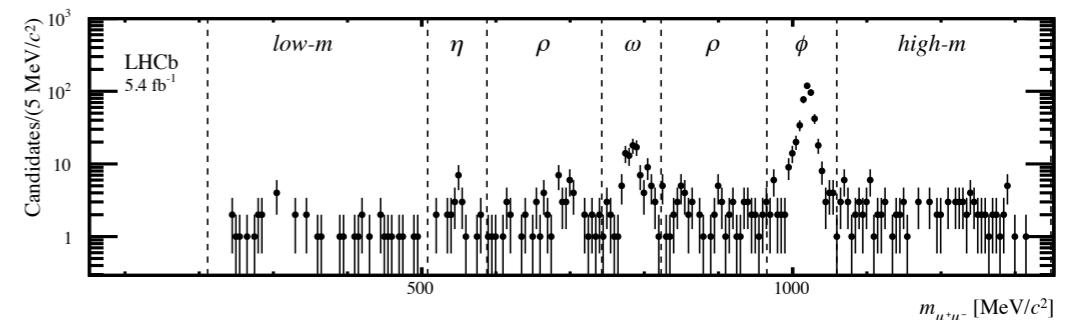
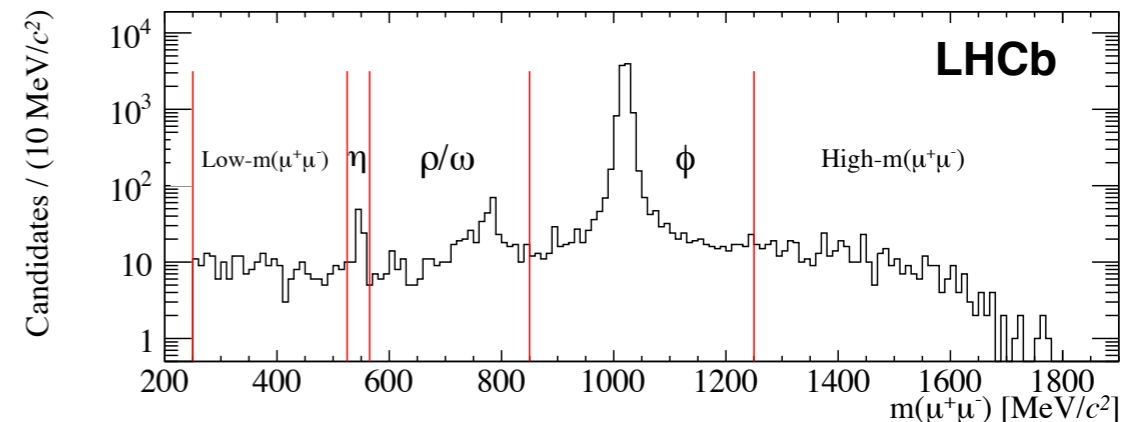
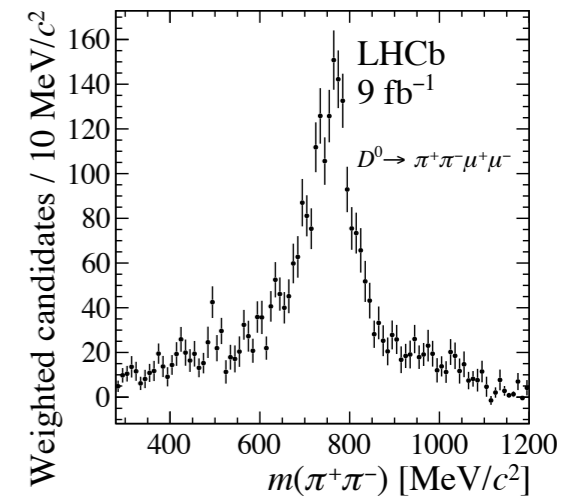
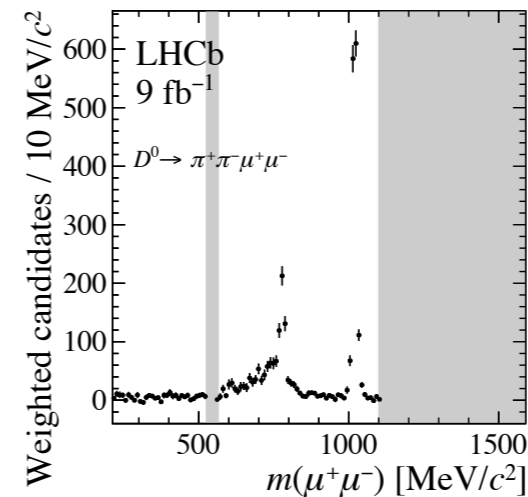


# What do we want to do?



New postdoc starting soon:  
Carolina Bolognani, MSc in  
LHCb, PhD in theory with  
Keri (CMF partner!)

- Will work on asymmetries in  $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ , strong also with strong background in theory will help to bridge experiment and pheno/theory
- **With CMF, we want to understand better dimuon (+dihadron) mass spectra to interpret our results of the null-tests!**
- Tricky backgrounds  $D \rightarrow h(h)\pi\pi$ ,  $\Lambda_c \rightarrow \rho\pi\pi$  require good understand of these decays, too
- Talking to Thomas et al: Missing information:  $D \rightarrow \pi V'$ ,  $V' = \rho', \phi'$ . Inputs from BESIII?
- Other tricky backgrounds: SL and radiative decays: Better understanding BESIII, BelleII <sup>8</sup>



# Beyond: Opportunities to discuss?

- Charm hadron lifetimes? Not our current focus, but open for discussions
- Charm baryon CPV? Two body modes with neutrals, not ideal at LHCb, but certain opportunities exist, in particular on the mid term
- How can we advance knowledge on charm CPV? Control modes, additional decays?  
Alex and others in Siegen? First attempts to work on two body charm decays on the lattice, also interest in RD mentioned (Andreas J.)  
Other multi-body decays?
- How much interest in mixing and time-dependent CPV?
- Many more possibilities in rare decays such as search for long-lived heavy neutrinos. Synergies with radiative decays (Belle II BESIII) in light of global analyses