BEAUTY 2018

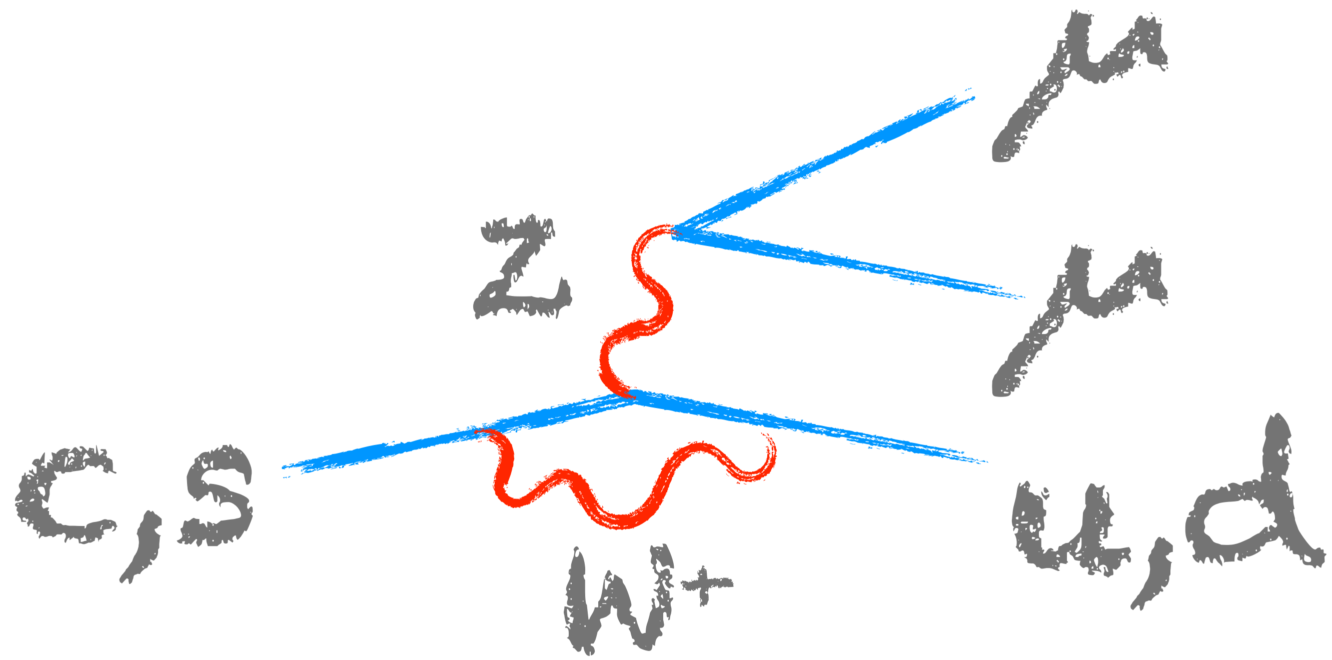
La Biodola (Elba), Italy
May 6-11 2018

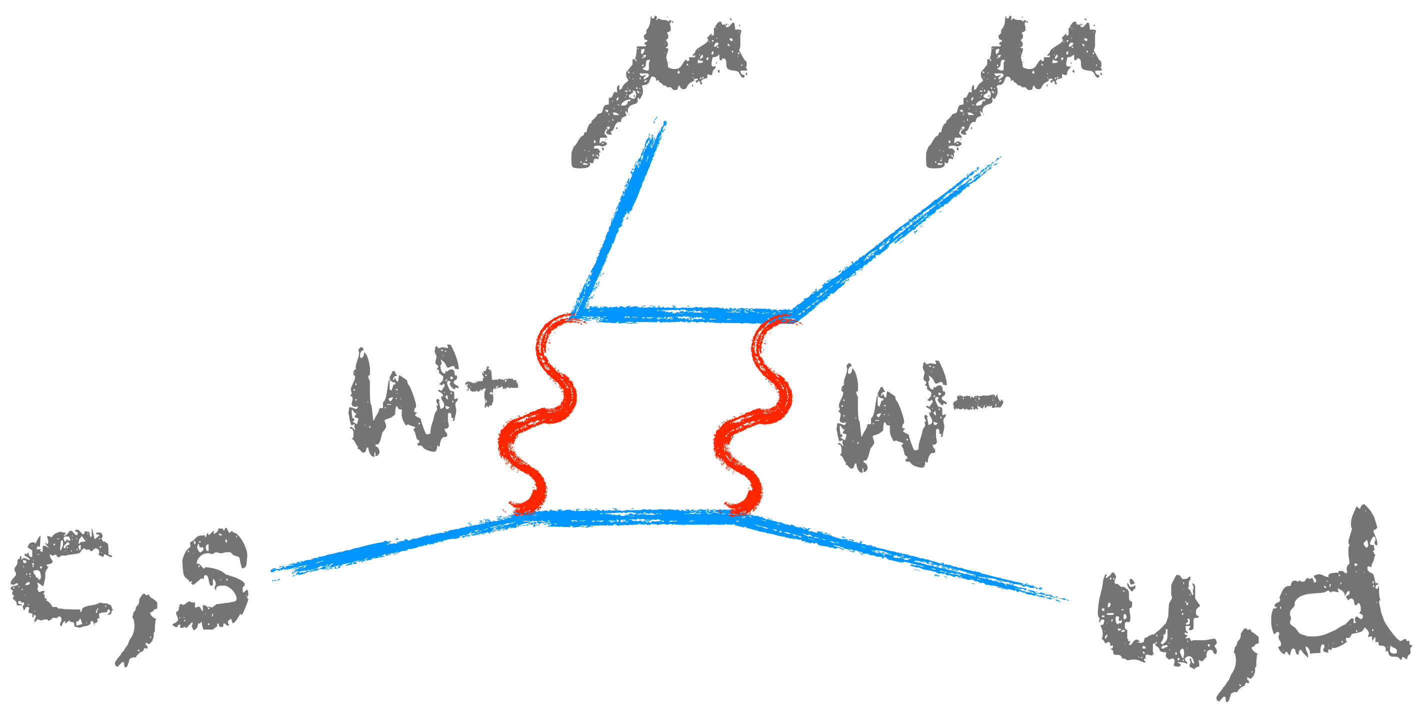
Rare charm and strange decays

Angelo Di Canto
on behalf of the LHCb Collaboration

Why?

- Rare charm and strange decays proceed through highly suppressed loops in the SM $\Longrightarrow$ ideal probes of NP
- Complementary to rare beauty decays
  - Best sensitivity to non-MFV NP due to the strong CKM suppression
  - Charm also probes couplings to up-type quarks
- Drawback is that long-distance (tree-level) contributions are non-negligible

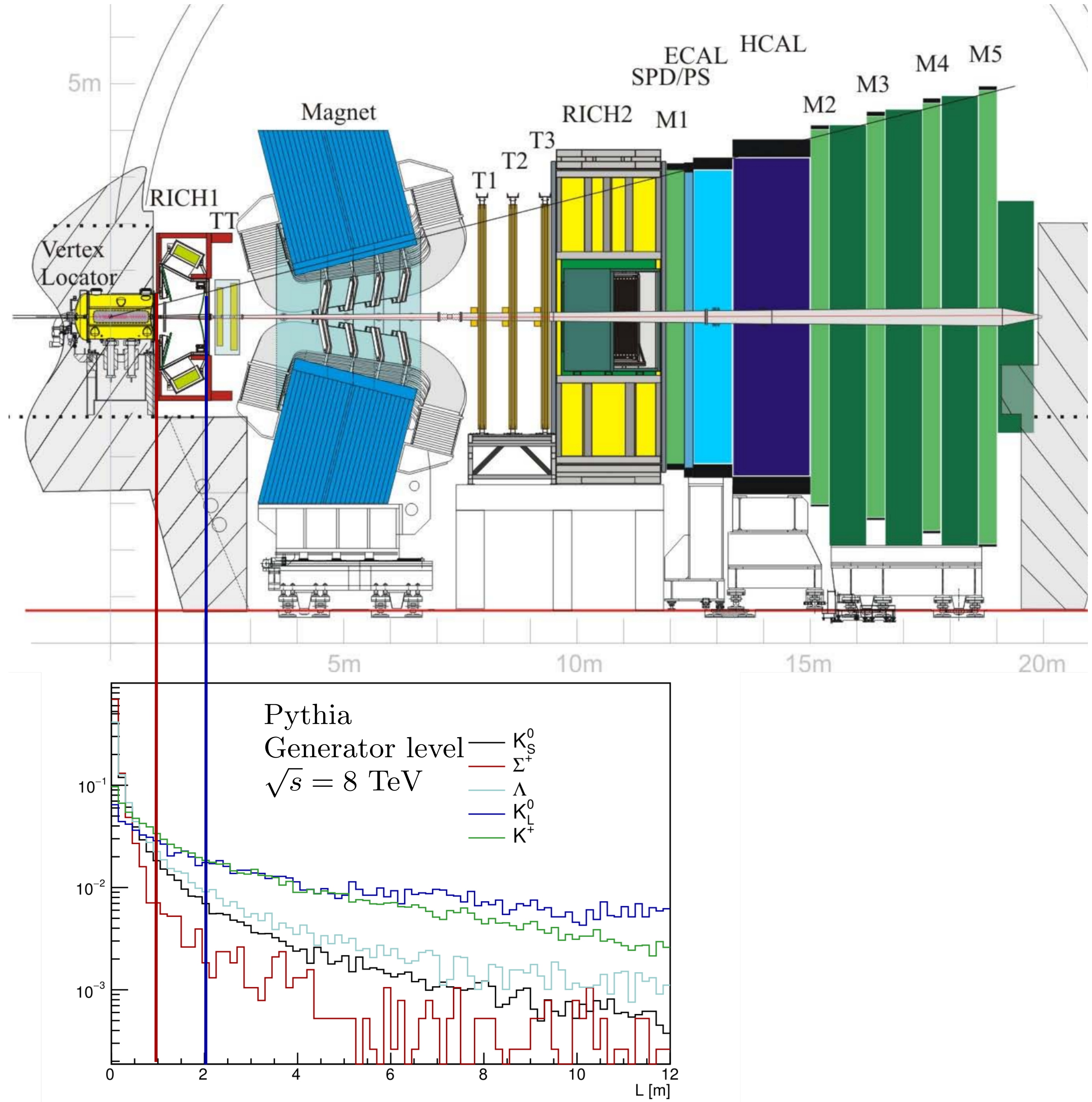




Rare strange

Strange decays at LHCb

- Extremely huge production rate at LHCb: O(1) strange hadron per collision
- However, strange particles have
  - large decay time (many decays outside of the acceptance)
  - low-momentum final state particles (while LHCb trigger is designed for higher-momentum heavy-flavored decays)
- Still there is potential for a rich physics program, especially in the upgrade(s) era



Search for $K_S \to \mu^+\mu^-$

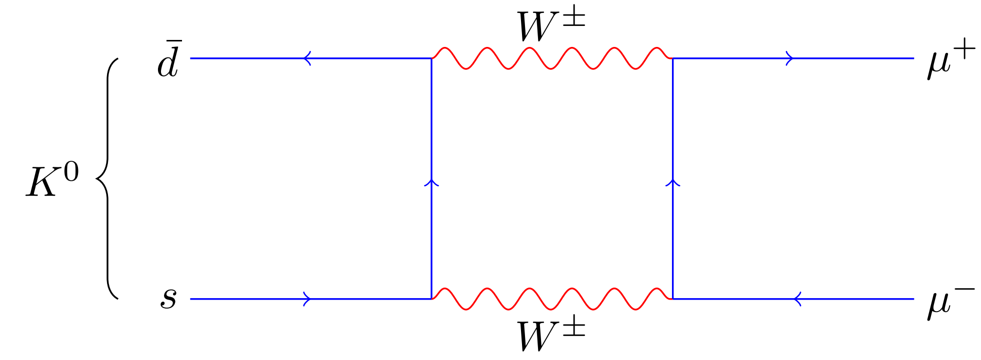
- Similar to $K_L \to \mu^+\mu^-$ (with which can interfere), but additionally suppressed by CPV
    - SM branching fraction predicted at about 5×10^{-12}, dominated by long-distance contributions
- Best limit before LHCb [PLB 44 (1973) 217]

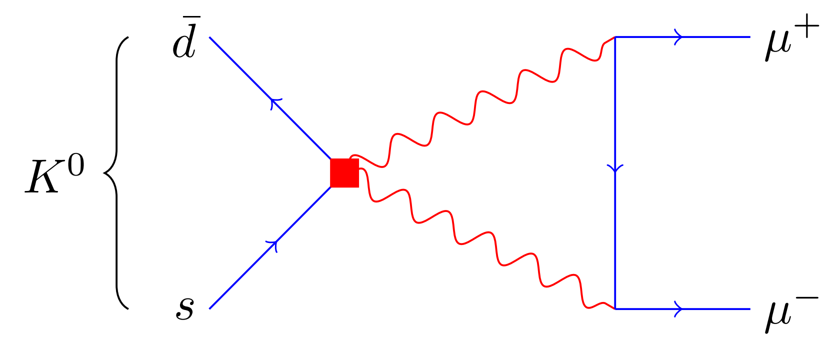
$$\mathcal{B}(K^0_S \to \mu^+\mu^-) < 3.1 \times 10^{-7} \quad 90\%\ \mathrm{CL}$$

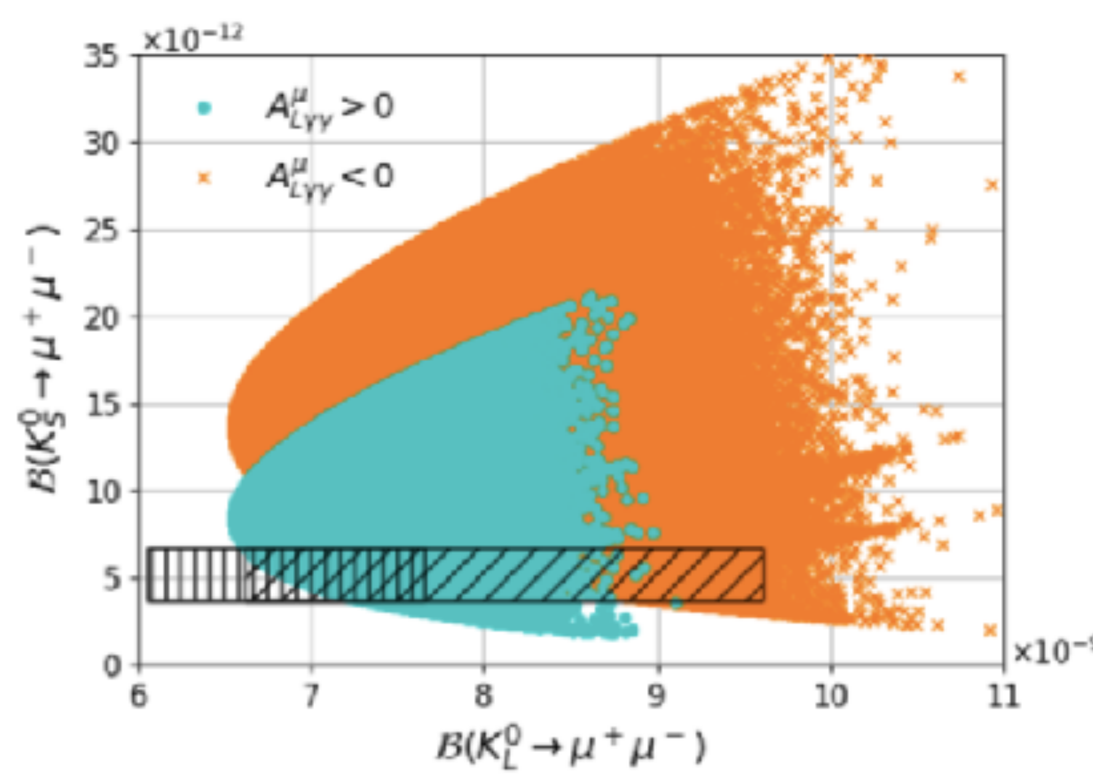
- Improved by LHCb in 2013 using 1/fb of Run 1 data [JHEP 01 (2013) 090]

$$\mathcal{B}(K^0_S \to \mu^+\mu^-) < 0.9 \times 10^{-8} \quad 90\%\ \mathrm{CL}$$

- Revived theoretical interest following LHCb results [see talk by G. D'Ambrosio]







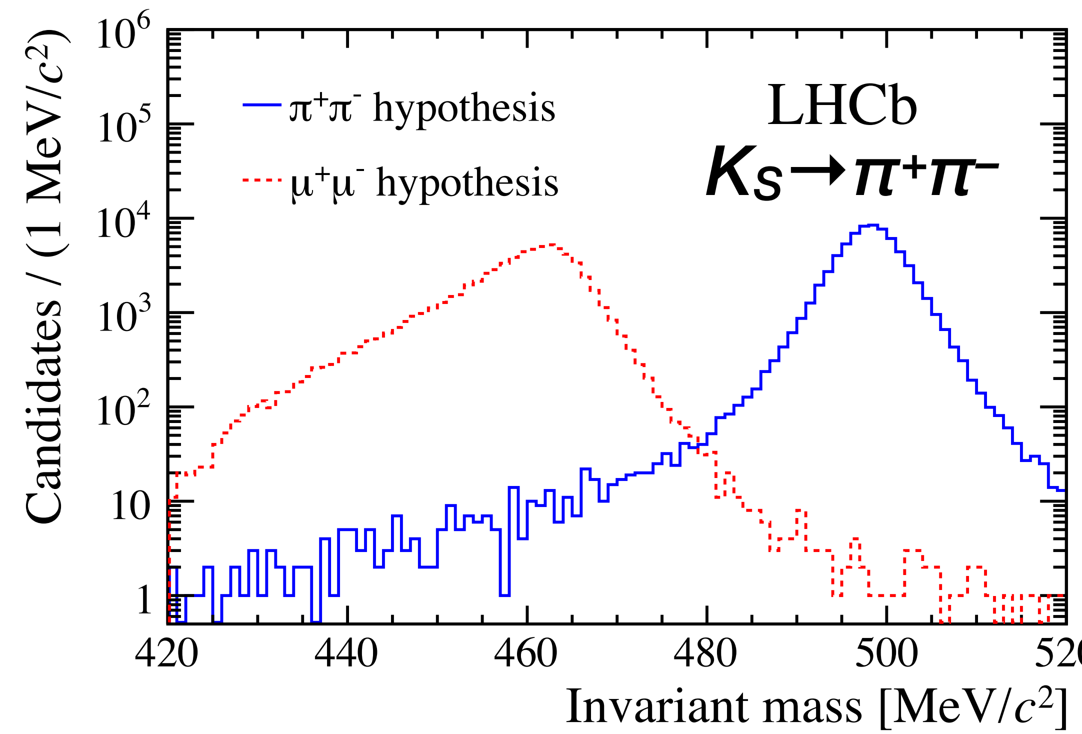
Search for $K_S \to \mu^+\mu^-$

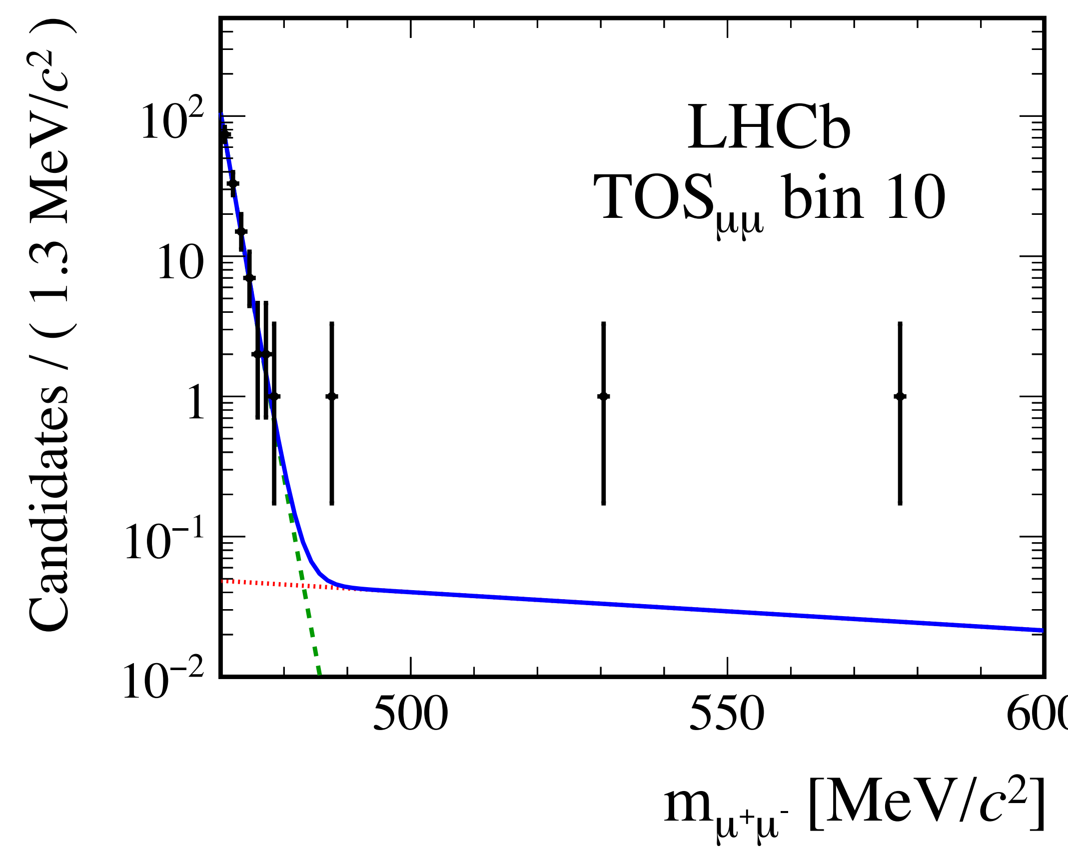
[EPJ C 77 (2017) 678]

- Result based on 3/fb of Run 1 data
- Normalise BF with respect to $K_S \to \pi^+\pi^-$, which is also the main background (suppressed with dedicated particle identification)
- Fit mass in bins of an MVA discriminant against combinatorial background
- Upper limit improves significantly (~400×) with respect to pre-LHCb era

$$\mathcal{B}(K_S^0 \to \mu^+\mu^-) < 0.8 \times 10^{-9} \quad 90\%\ \mathrm{CL}$$

- Interesting prospects for the future: sensitivity could reach SM value in the upgrade(s)





The HyperCP anomaly in $\Sigma^+ \to p\mu^+\mu^-$

- Short-distance SM branching fraction is at O(10^{-12}), long-distance contribution up to 10^{-7}

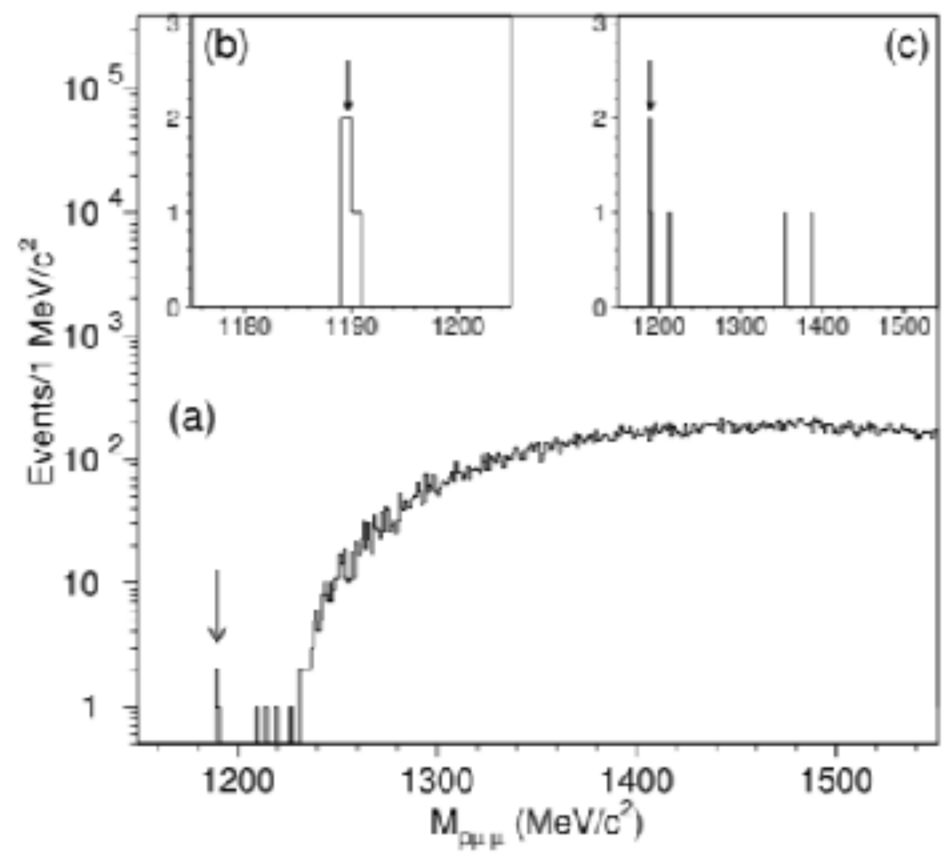
- First evidence reported by HyperCP with 3 events in absence of background

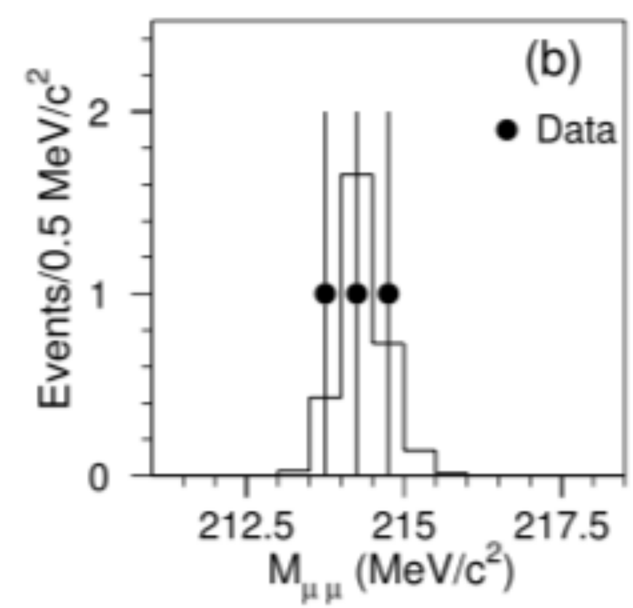
$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5) \times 10^{-8}$$

- All events clustered at the same dimuon mass of (214.3±0.5) MeV/c^2, indicating the existence of a new particle $P^0 \to \mu^+\mu^-$

- P^0 searched for and not found by several experiments using dimuons from different decays

[PRL 94 (2005) 021801]



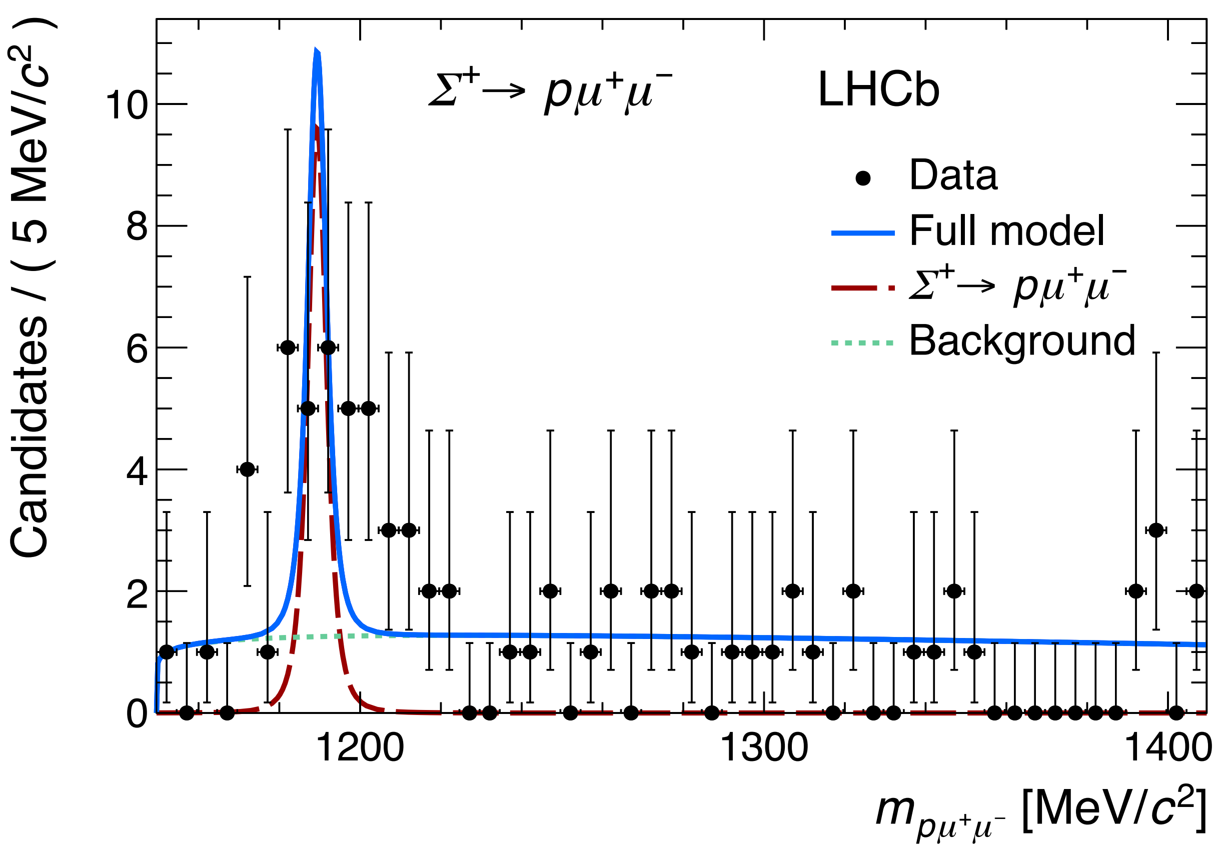


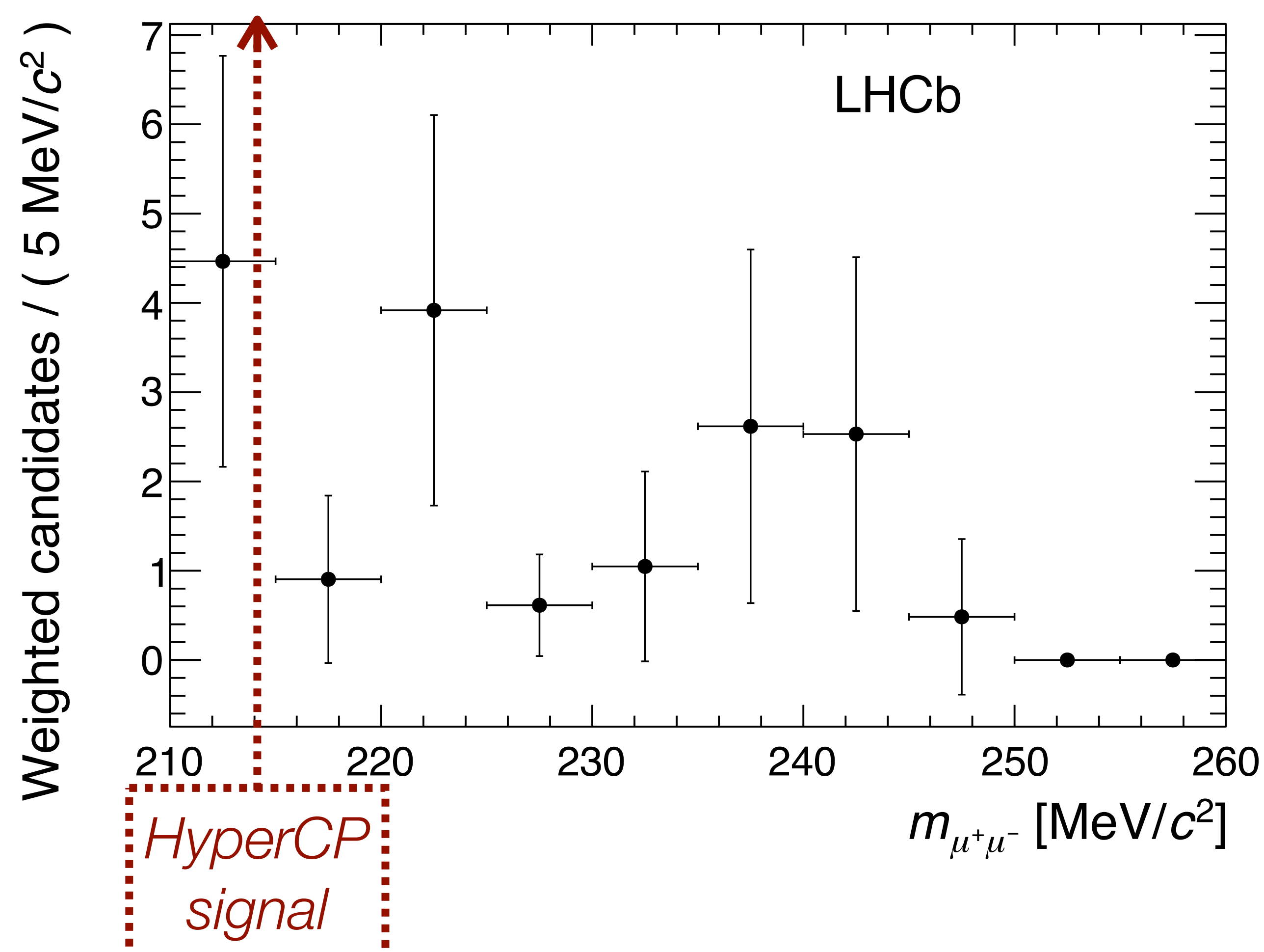
Search for $\Sigma^+ \rightarrow p\mu^+\mu^-$ at LHCb

[arxiv:1712.08606]

- Searched in 3/fb of Run 1 data
- Evidence for the decay at 4σ, no structure observed in $m(\mu^+\mu^-)$

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (2.1^{+1.6}_{-1.2}) \times 10^{-8}$$

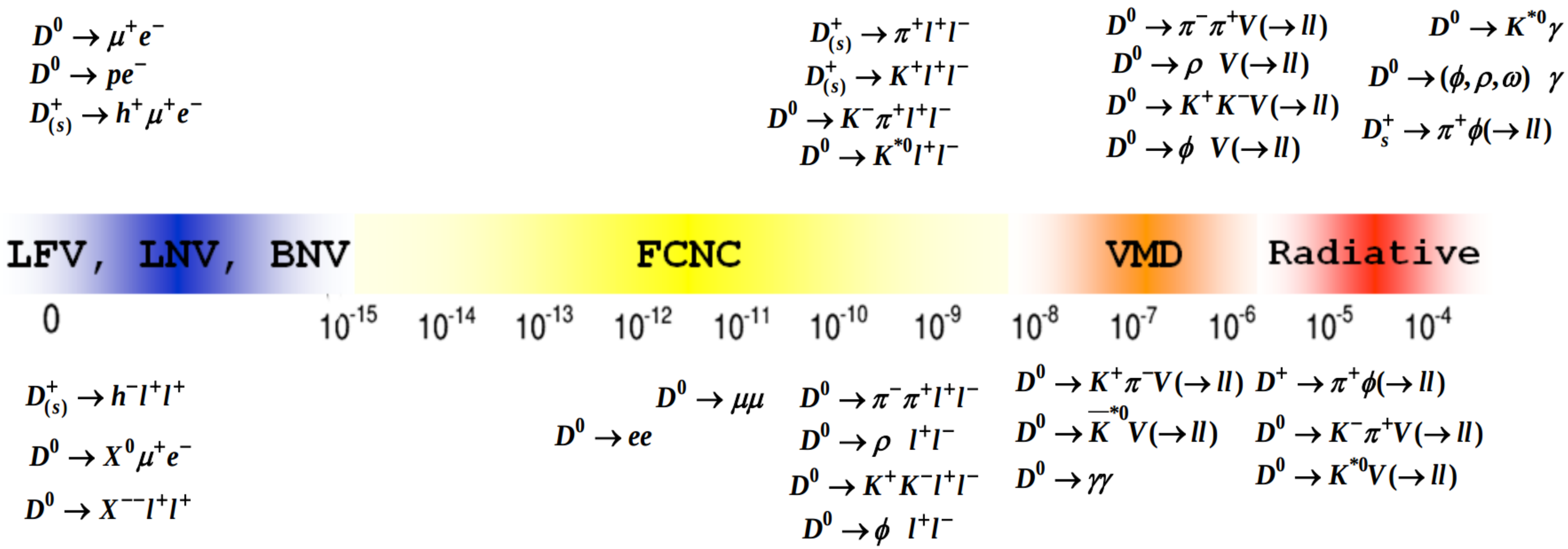




Rare charm

Rare charm decays at LHCb

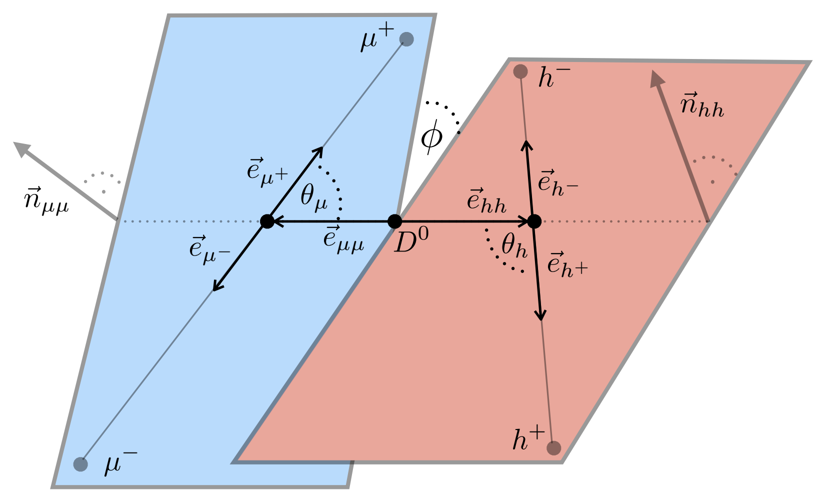
- A rainbow of different physics, ranging from forbidden to (not-so-rare) radiative decays

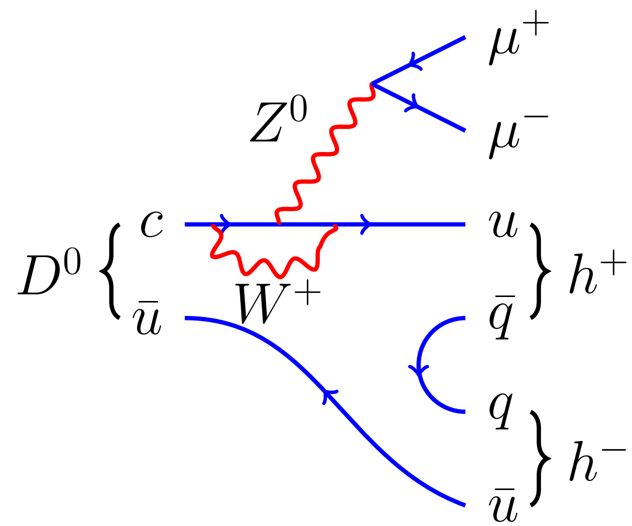


- So far LHCb focused mostly on final states with 2 muons:
  - Best limit on $D^0 \to \mu^+\mu^-$ [PLB 725 (2013) 15], $D_{(s)} \to \pi^+\mu^+\mu^-$, $\pi^-\mu^+\mu^+$ [PLB 724 (2013) 203], $D^0 \to h^+h^-\mu^+\mu^-$ [PLB 728 (2014) 234], $D^0 \to e^+\mu^-$ [PLB 754 (2016) 167], $\Lambda_c \to p\mu^+\mu^-$ [PRD 97 (2018) 091101]
  - First observation of $D^0 \to K^-\pi^+V(\to\mu^+\mu^-)$ [PLB 757 (2016) 558], $K^+K^-V(\to\mu^+\mu^-)$, $\pi^+\pi^-V(\to\mu^+\mu^-)$ [PRL 119 (2017) 181805], $\Lambda_c \to pV(\to\mu^+\mu^-)$ [arxiv:1712.07938]

The richness of $D^0 \to h^+h^-\mu^+\mu^-$ decays

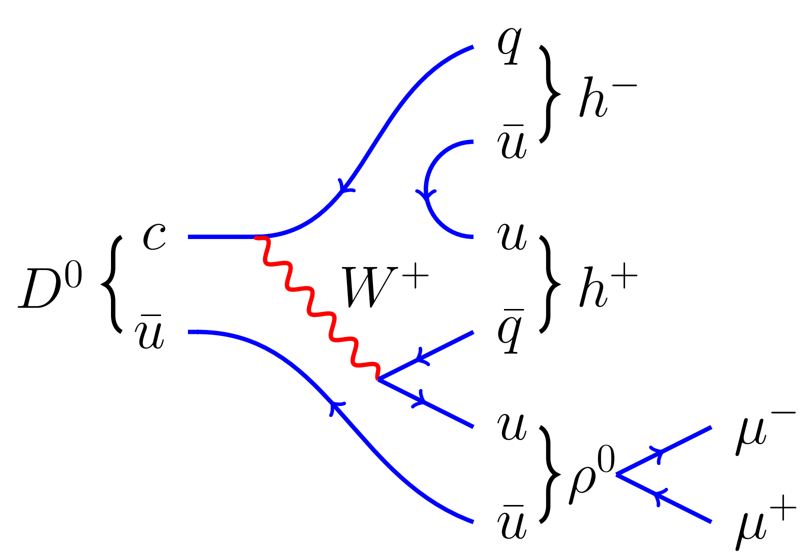
- Overwhelming contribution from long-distance amplitudes proceeding through intermediate vector resonances in the dimuon spectrum
- Such penalty is overly compensated by the rich and diverse dynamics of multibody decays





example short-distance contribution
EW penguin

  - Access to angular and CP asymmetries can greatly increase sensitivity to short-distance physics
    - O(1%) asymmetries may be generated by NP [JHEP 04 (2013) 135, PRD 87 (2013) 054026]

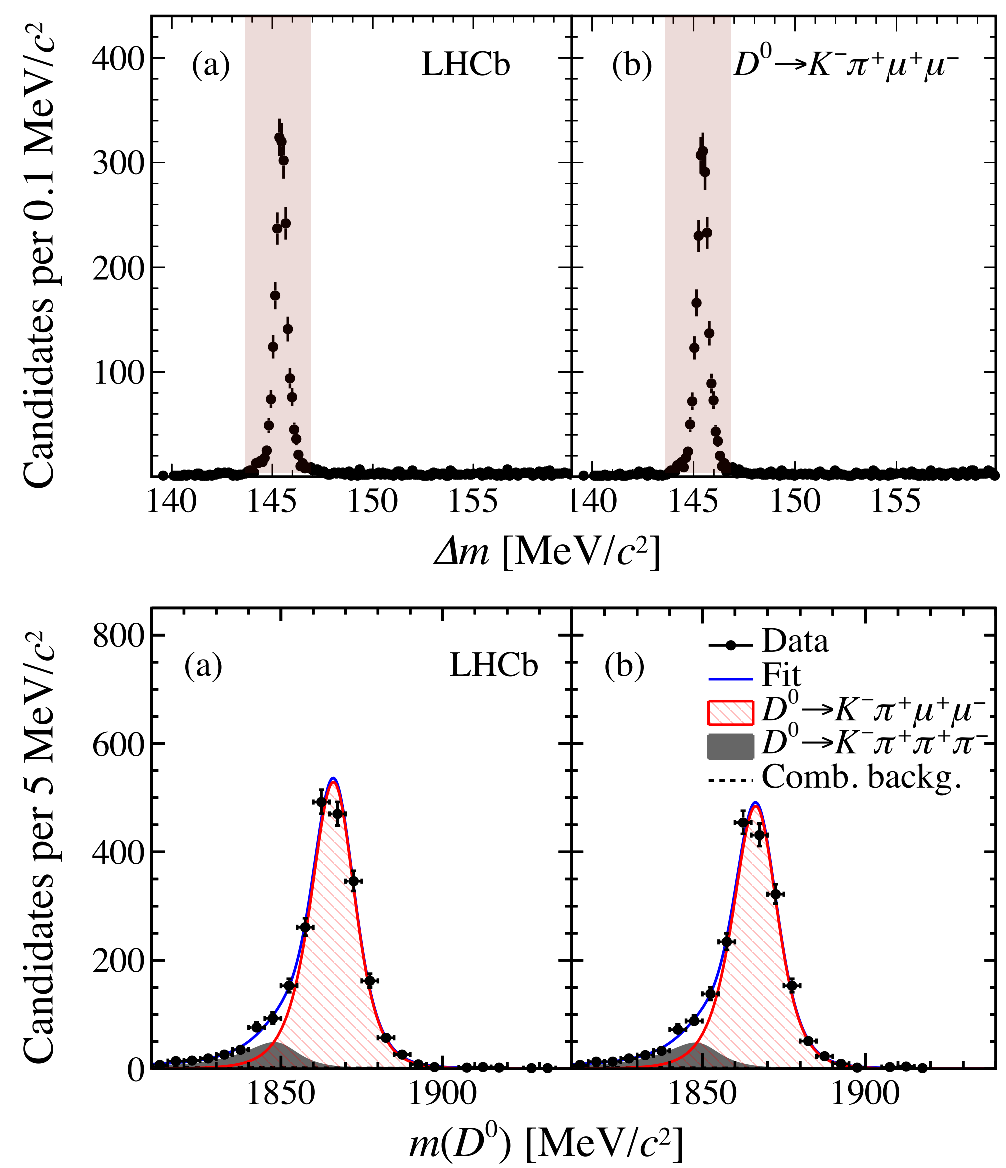


example long-distance contribution
$D^0 \to h^+h^-\rho^0(\to\mu^+\mu^-)$

$D^0 \to h^+h^-\mu^+\mu^-$ decays at LHCb

[PRL 119 (2017) 181805]

- Search for $D^0 \to h^+h^-\mu^+\mu^-$ decays using 2/fb of Run 1 data
- Use $D^{*+} \to D^0\pi^+$ decays to greatly suppress combinatorial background
- Dominant background is then due to misidentified hadronic decays
- Look for signal in bins of dimuon mass and measure/set limit on branching fraction relative to $D^0 \to K^-\pi^+\rho/\omega(\to\mu^+\mu^-)$

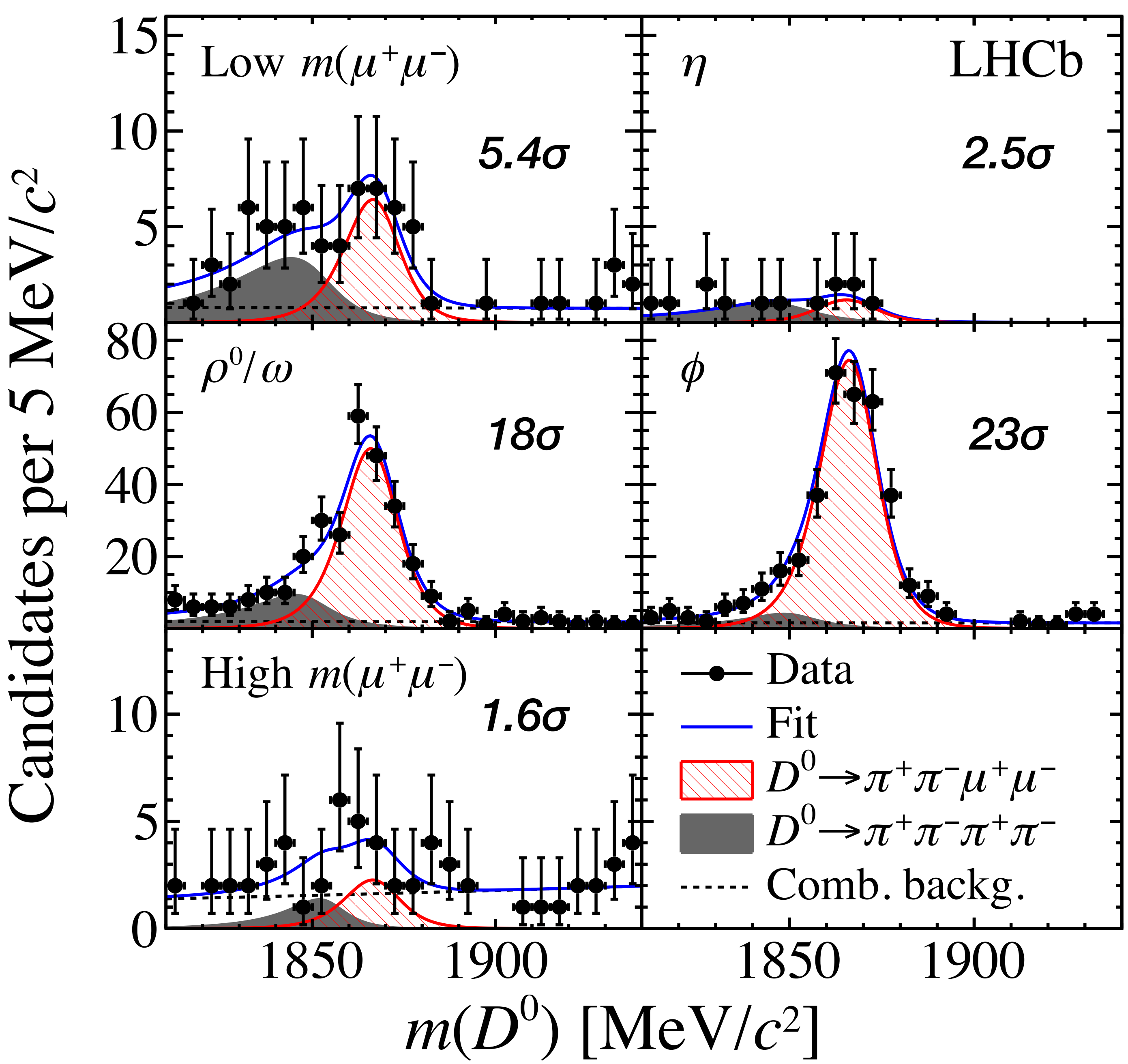


bin	low mass	η	ρ/ω	ϕ	high mass
$m(\mu^+\mu^-)[MeV/c^2]$	< 525	$525 - 565$	$565 - 950$	$950 - 1100$	> 1100
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	✓	✓	✓	✓	✓
$D^0 \to K^+K^-\mu^+\mu^-$	✓	✓	✓		

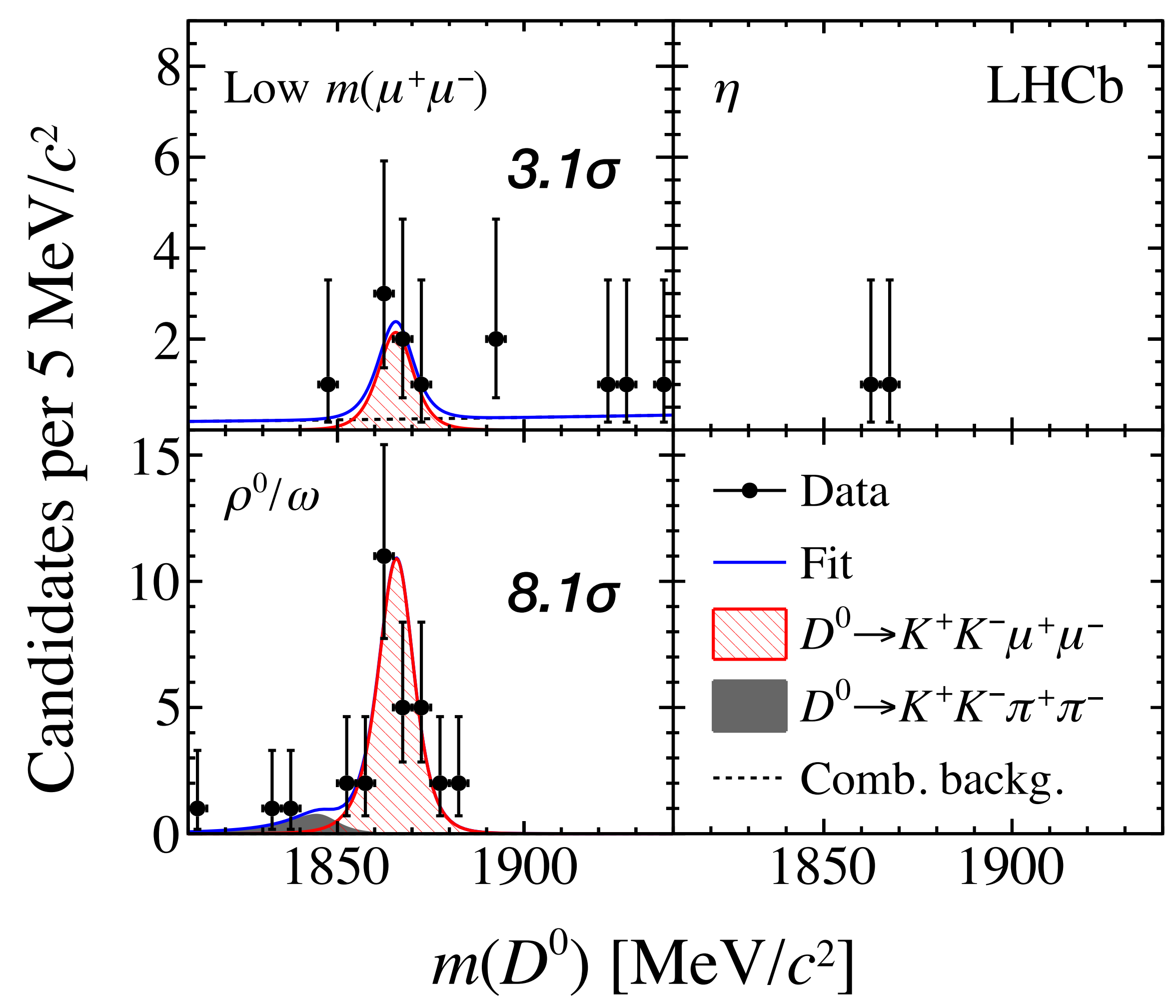
Signals in bins of dimuon mass

[PRL 119 (2017) 181805]

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

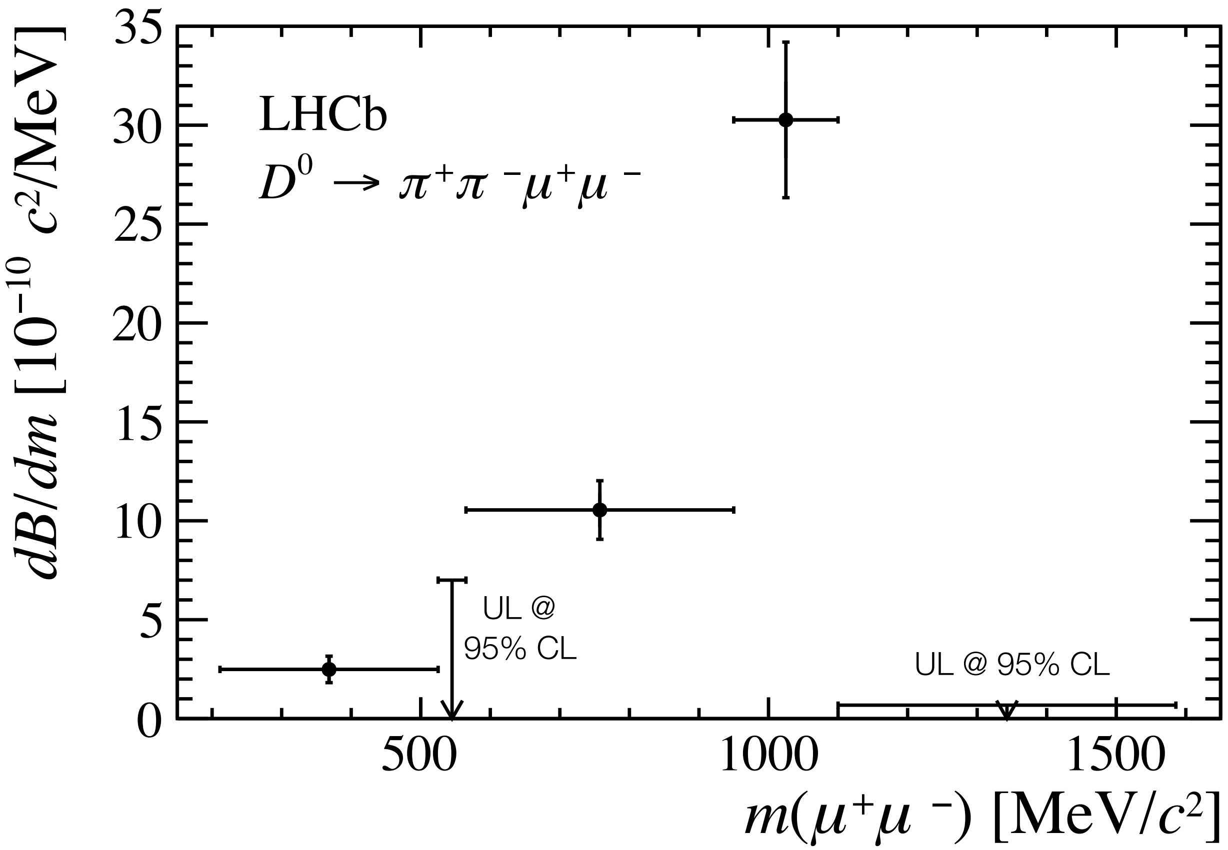


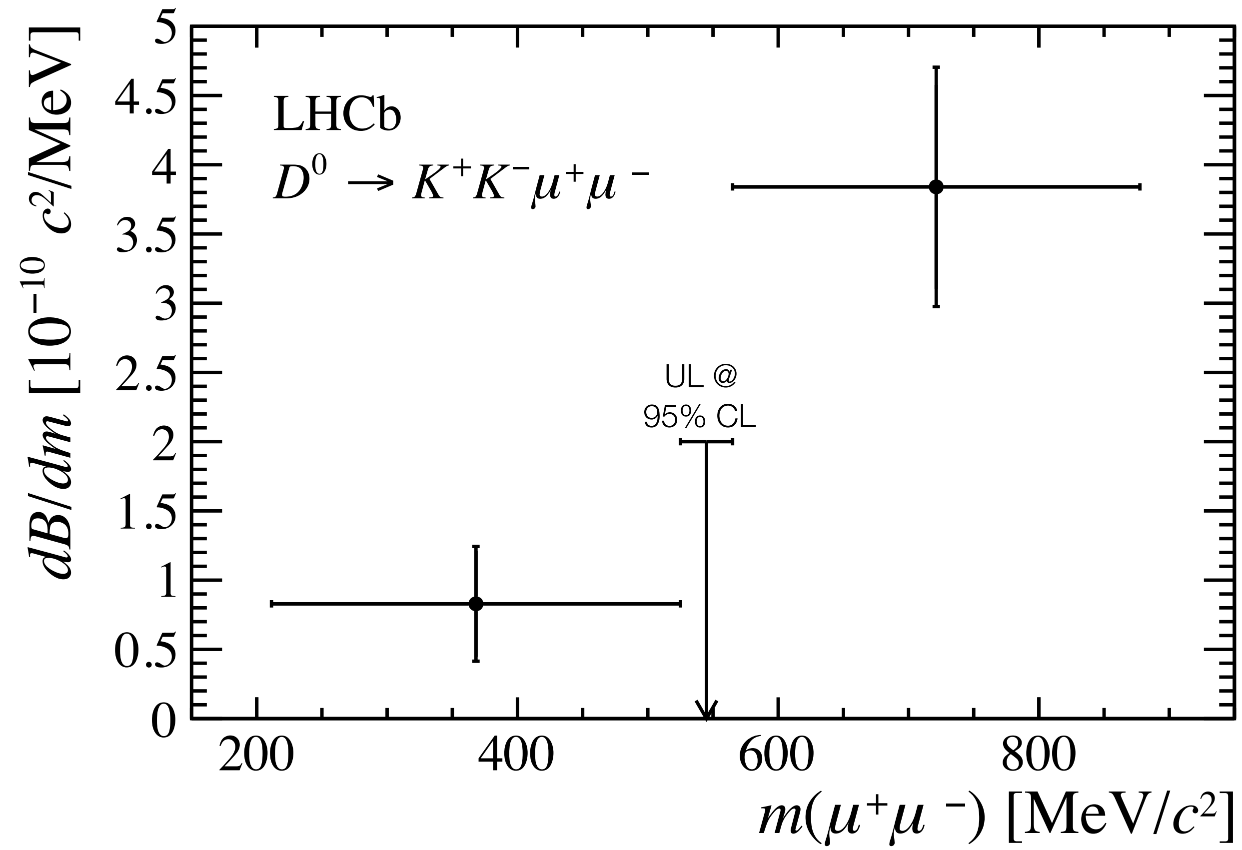
$D^0 \to K^+K^-\mu^+\mu^-$



Results

[PRL 119 (2017) 181805]





- Rarest charm-hadron decays ever observed:

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

$$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$$

where the uncertainties are statistical, systematic and due to the BF of the normalisation

- Branching fractions in broad agreement with SM predictions [JHEP 04 (2013) 135]

Prospects for angular and CP asymmetries

- Having seen these four-body decays we can now measure angular and CP asymmetries

- Analyses are ongoing for $D^0 \to h^+h^-\mu^+\mu^-$ decays, expected sensitivities look already interesting for Run 2

Decay mode	Run 2 (9/fb)		Upgrade (50/fb)	
	Yield	$\sigma(A)$	Yield	$\sigma(A)$
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	3.6k	2%	18.5k	1%
$D^0 \to K^+K^-\mu^+\mu^-$	380	7%	1.9k	3%

Search for $\Lambda_c \to p\mu^+\mu^-$

[PRD 97 (2018) 091101]

- Search performed with 3/fb of Run 1 data and using $\Lambda_c \to p\phi(\to\mu^+\mu^-)$ as normalisation

- Upper limit on non-resonant component

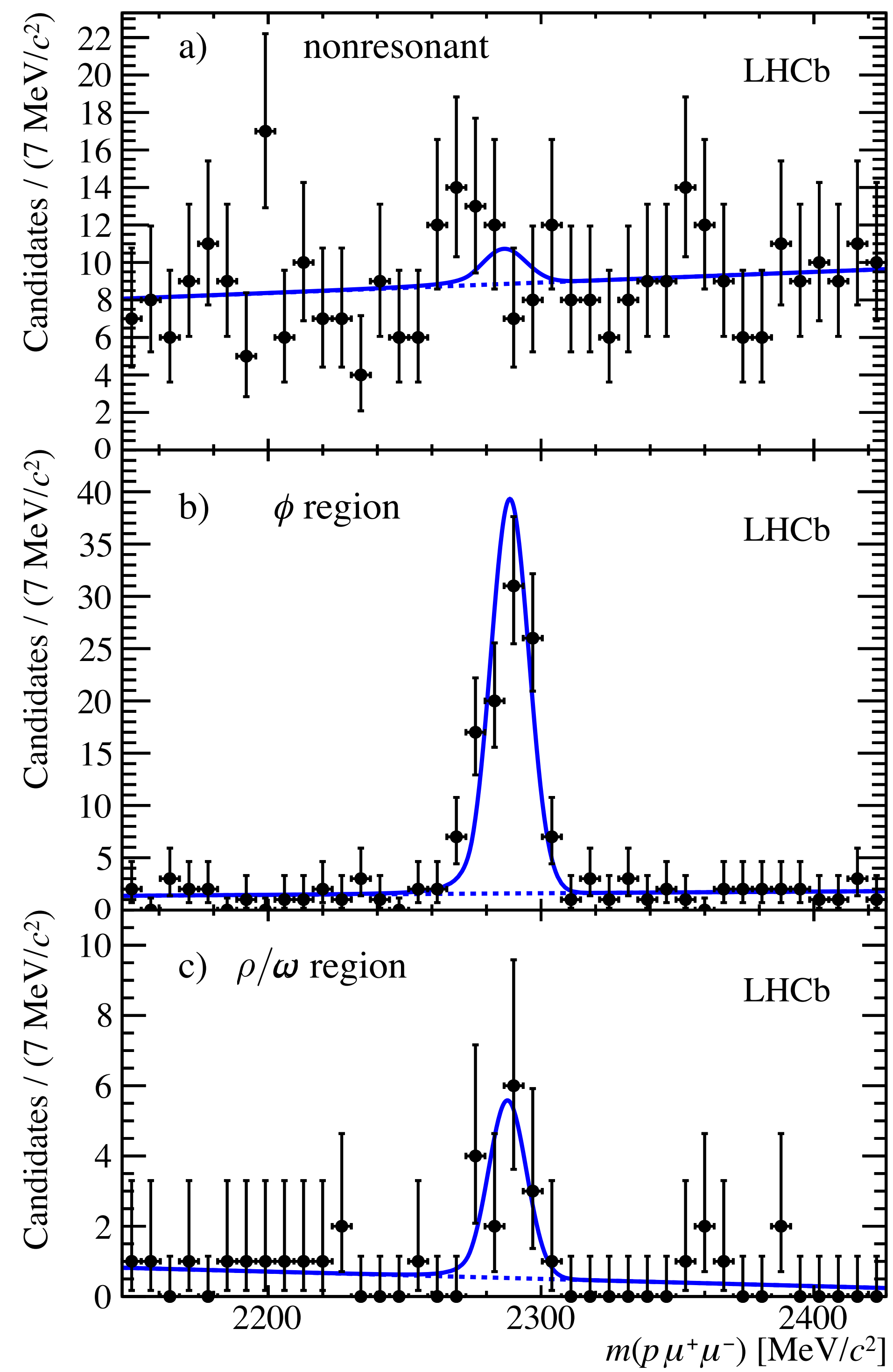
$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 9.6 \times 10^{-8} \quad 95\% \text{ CL}$$

~1000× better than previous result from BaBar [PRD 84 (2011) 072006]

- First observation of $\Lambda_c \to p\mu^+\mu^-$ in the ρ/ω region of the dimuon spectrum

$$\mathcal{B}(\Lambda_c^+ \to p[\mu^+\mu^-]_{\rho/\omega}) = (9.4 \pm 3/2 \pm 1.0 \pm 2.0) \times 10^{-4}$$

where the uncertainties are statistical, systematic and due to the BF of the normalisation



Concluding remarks

Conclusions

- Not just beauty: rare decays at LHCb are also strange and charming
- Steady progress over the year, with LHCb having improved by orders of magnitude over previous searches
  - Seen signals of four-body charm decays into two muons and two hadrons, now moving into measuring angular and CP asymmetries with sensitivity of a few % already in Run 2
  - The rare strange program is at its start, but has large potential in the upcoming LHCb upgrade(s)
  - Focused mostly on final states with muons, but started to look also into electrons
- Hoping for exciting results to come…

Thanks