Searches for rare charm decays at LHCb

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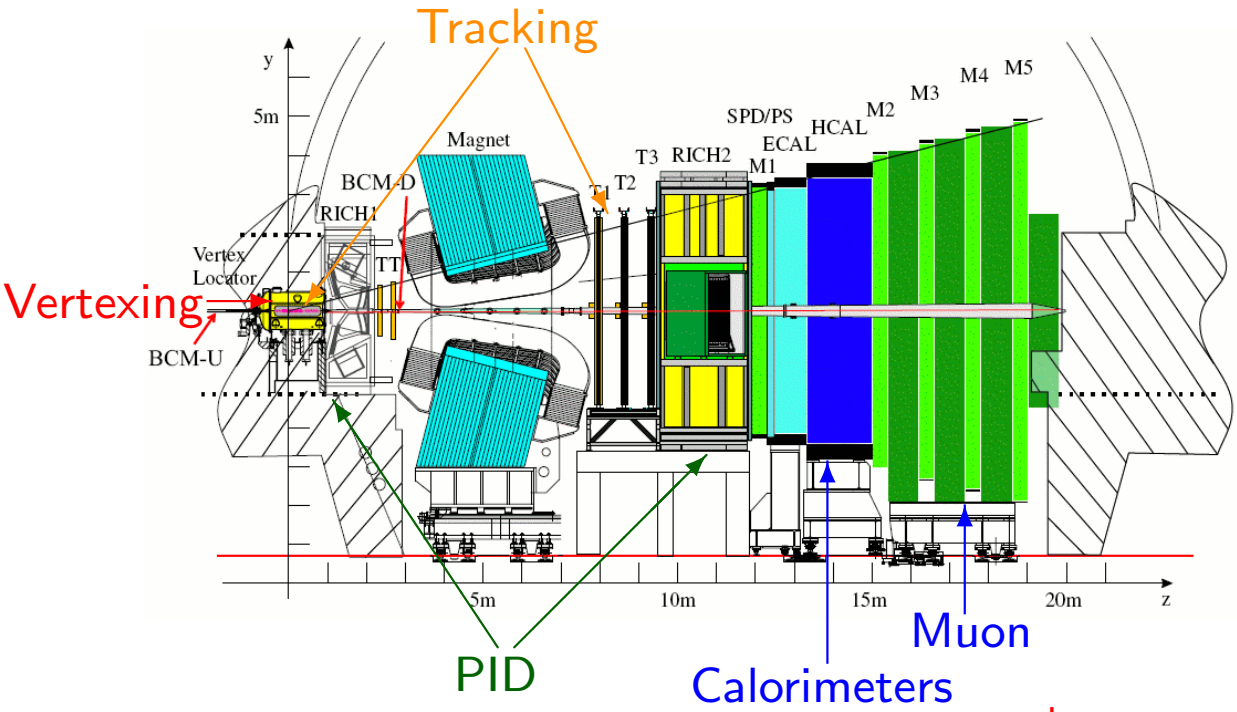
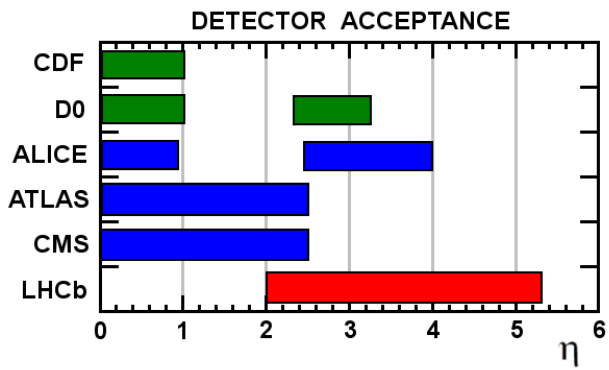
Topics

1. Introduction
2. Search for the $D^0 \to \pi^+\pi^-\mu^+\mu^-$ decay
3. First observation of the decay $D^0 \to K^-\pi^+\mu^-\mu^+$ in the ρ^0/ω region in the dimuon mass spectrum
4. Search for the $D^0 \to e^+\mu^-$ decay
5. Observation of $\eta_c(2S) \to p\bar{p}$ and search for $X(3872) \to p\bar{p}$ decays
6. Conclusions and Prospects

Reminder of the LHCb detector [JINST 3 (2008) S080005]

LHCb proved itself to be a forward general purpose detector at the LHC:





Large cross sections ($p_T < 8\,\mathrm{GeV}/c, 2.0 < y < 4.5$):

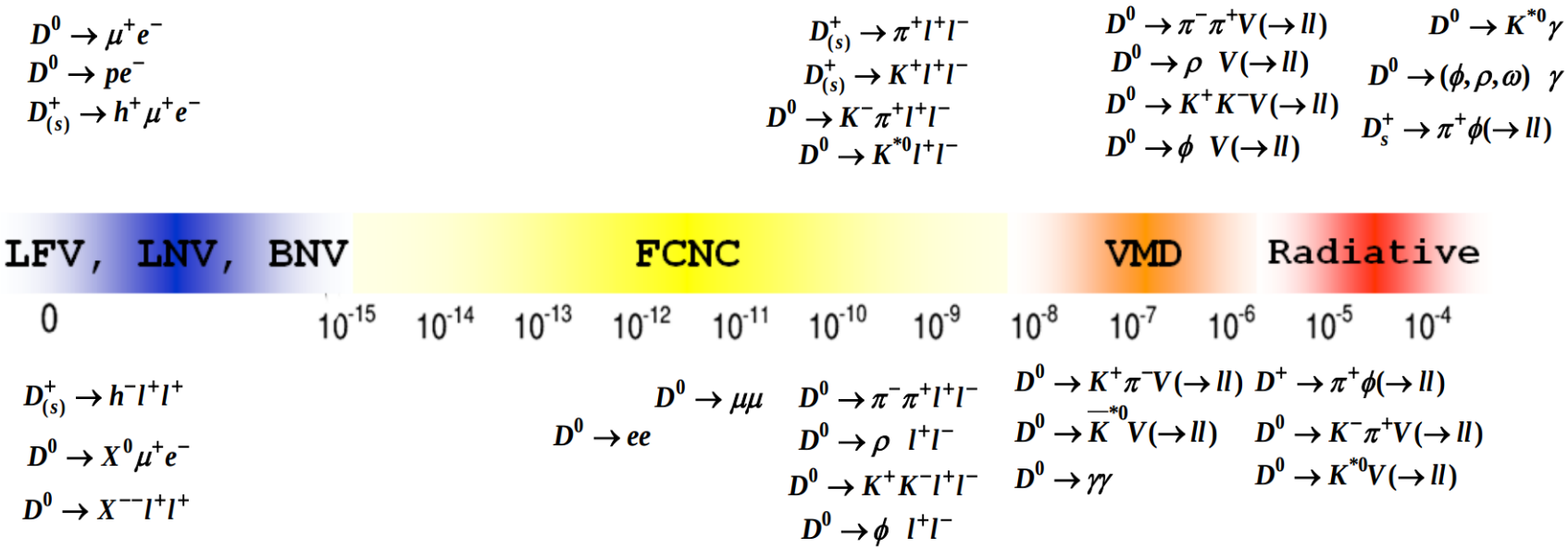
$\sigma(c\bar{c}, \sqrt{s} = 7\,\mathrm{TeV}) = 1419 \pm 133\,\mu\mathrm{b}$ [Nuc Phys B871 (2013), pp. 1-20]

$\sigma(c\bar{c}, \sqrt{s} = 13\,\mathrm{TeV}) = 2940 \pm 240\,\mu\mathrm{b}$ [JHEP03(2016)159]

- Performance:
  - $\Delta p/p = 0.35\% - 0.55\%$
  - Mass resolution$= 10 - 25\,\mathrm{MeV/c^2}$
  - Impact parameter resolution: $20\,\mu\mathrm{m}$ for high-p_T tracks
  - ECAL $\sigma(E)/E = 10\%(E/\mathrm{GeV})^{-1/2} \oplus 1\%$
  - Excellent particle ID thanks with RICH detectors (2-100 GeV/c^2)

Charm Rare Decays

Wide variety of physics, ranging from forbidden to not-so-rare decays

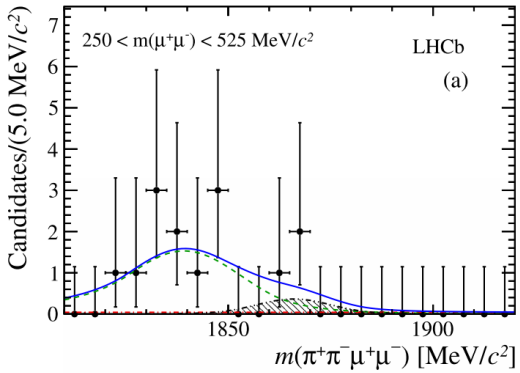


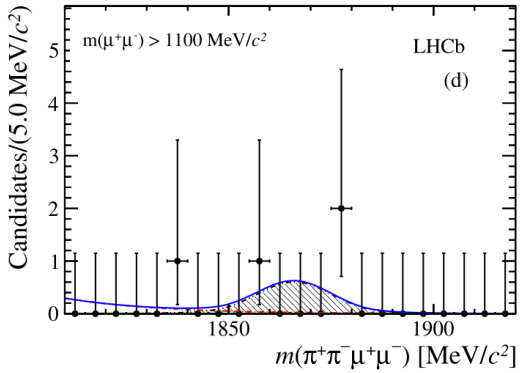
[PRD 66 (2002) 014009]

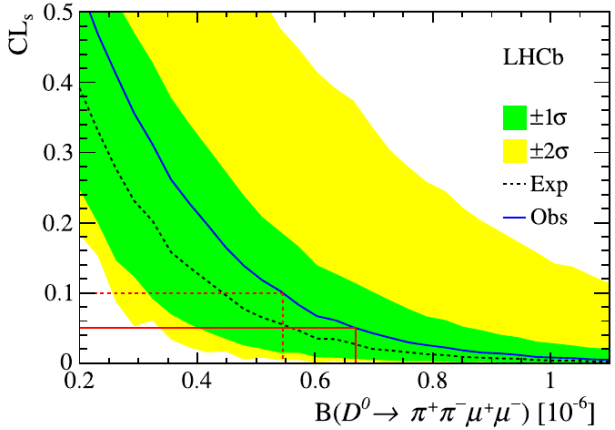
Short distance contributions to effective $c \to u$ transitions are tiny, branching fractions dominated by long distance contributions
SM predictions (for non-resonant decays) are normally $BF < 10^{-9}$, not yet there but will get very close after the LHCb upgrade

Search for the $D^0 \to \pi^+\pi^-\mu^+\mu^-$ decay [PLB 728 (2014) 234-243]

- First LHCb attempt to set limits for (non-resonant) 4-body rare charm
- Use 2011 data only (1fb^{-1}) and $D^{*\pm} \to D^0\pi^\pm$ decays to suppress combinatorial background
- Normalise to $D^0 \to \pi^+\pi^-\phi(\to \mu^+\mu^-)$ but branching fraction extracted from an amplitude analysis of $D^0 \to \pi^+\pi^-K^+K^-$ performed by CLEO $\to$ large systematic affecting the limit







- $BF(D^0 \to \pi^+\pi^-\mu^+\mu^-) < 5.5 \times 10^{-7}$ at 90% CL (world's best)

First observation of the decay $D^0 \to K^-\pi^+\rho^0/\omega(\to \mu^-\mu^+)$

[PLB 757 (2016) 558-567]

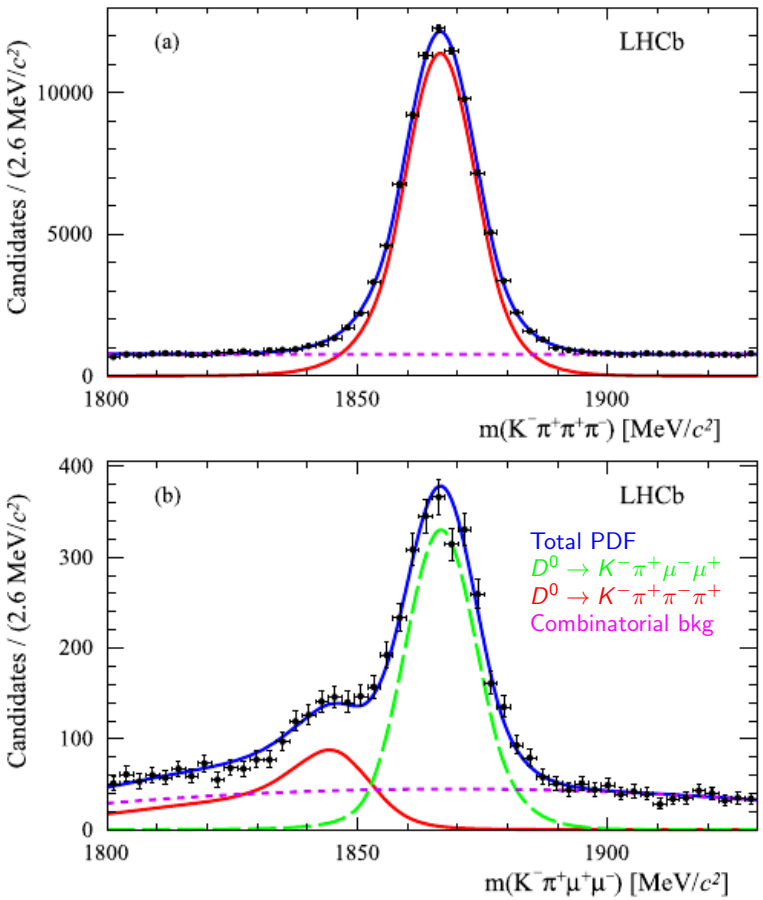
- Rare $D^0 \to h^+h^-l^+l^-$ decays sensitive to NP in the non-resonant regions of the dilepton spectrum
- FCNCs are the most interesting and $D^0 \to \pi^+K^-\mu^+\mu^-$ is not one of them...
- Still its resonant contributions provide an excellent normalisation for all the other 4 body modes

Analysis overview (2012 data, $2\,\mathrm{fb}^{-1}$)

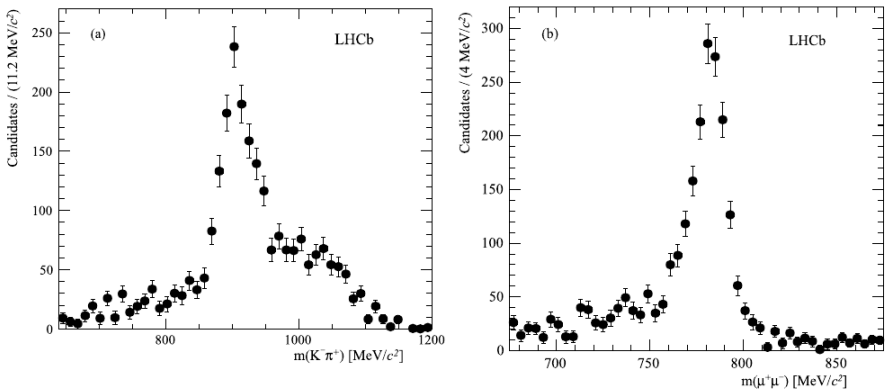
- Focus on $m(\mu\mu)$ in the ρ^0/ω region ($[675, 875]\,\mathrm{MeV}$)
- Normalise to $D^0 \to K^-\pi^+\pi^-\pi^+$ which is also the main background
- Careful estimation of peaking backgrounds

First observation of the decay $D^0 \to K^-\pi^+\rho^0/\omega(\to \mu^-\mu^+)$

[PLB 757 (2016) 558-567]



- $BF(D^0 \to K^-\pi^+\mu^-\mu^+) = (4.12 \pm 0.12_{stat} \pm 0.38_{syst}) \times 10^{-6}$
- In agreement with SM predictions [JHEP 04 (2013) 135]



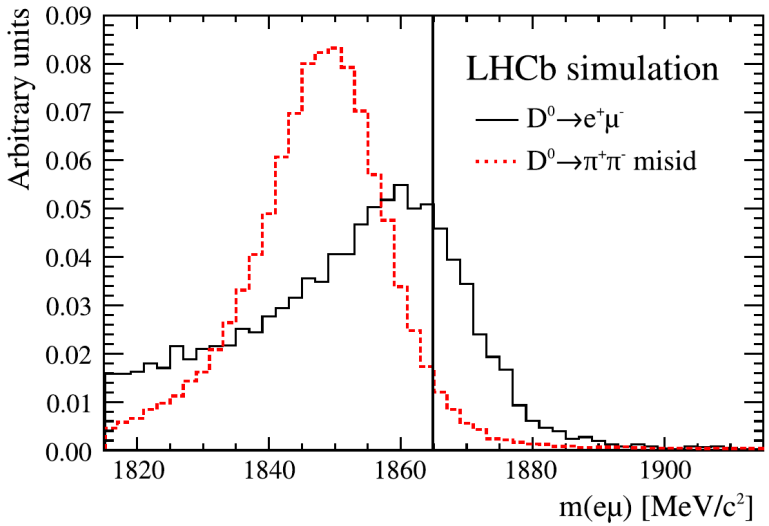
Search for the $D^0 \to e^+\mu^-$ decay [PLB 754 (2016) 167]

- Predicted to occur in R-parity violating MSSM

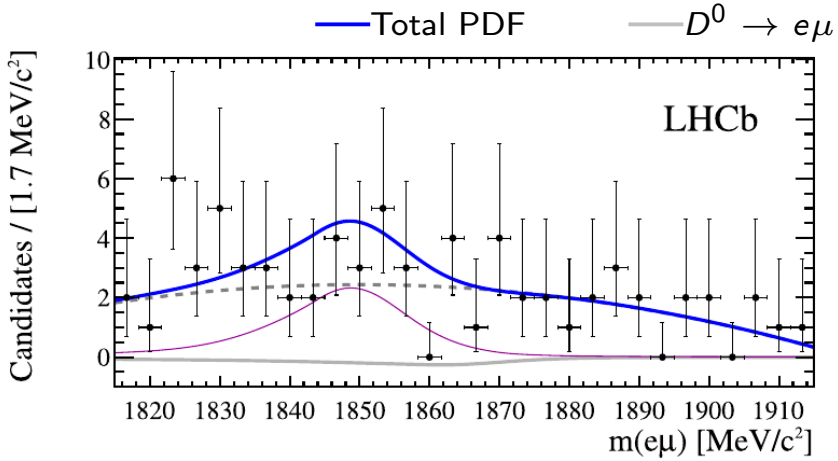
  [PRD 66, 014009, Int. J. Mod. Phys. A 29, 1450169 (2014)]
- Previous limits from BaBar (3.3×10^{-7} at 90% CL) and Belle (2.6×10^{-7} at 90% CL) [PRD 86, 032001, PRD 81, 091102(R)]

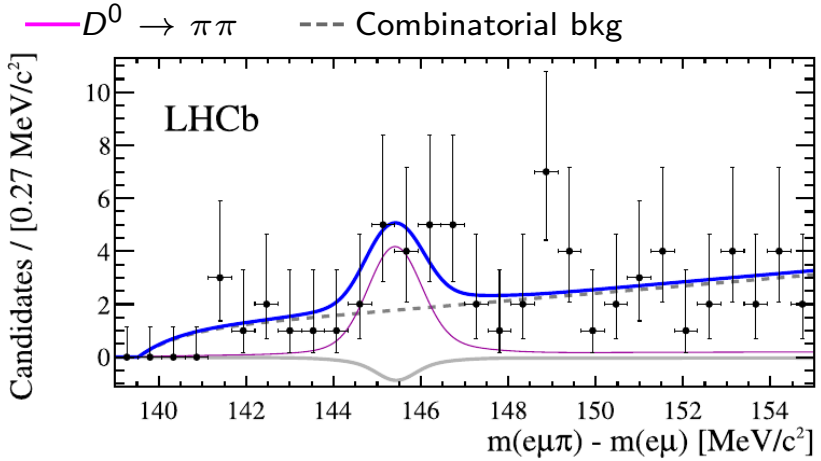
Analysis overview (Run 1 data, 3fb^{-1})

- Use $D^{*\pm} \to D^0\pi^\pm$ decays
- Normalised to $D^0 \to K^-\pi^+$ mode
- Analysis performed in bins of BDT
- Main issues from bremsstrahlung and shape of misidentified $D^0 \to \pi^+\pi^-$

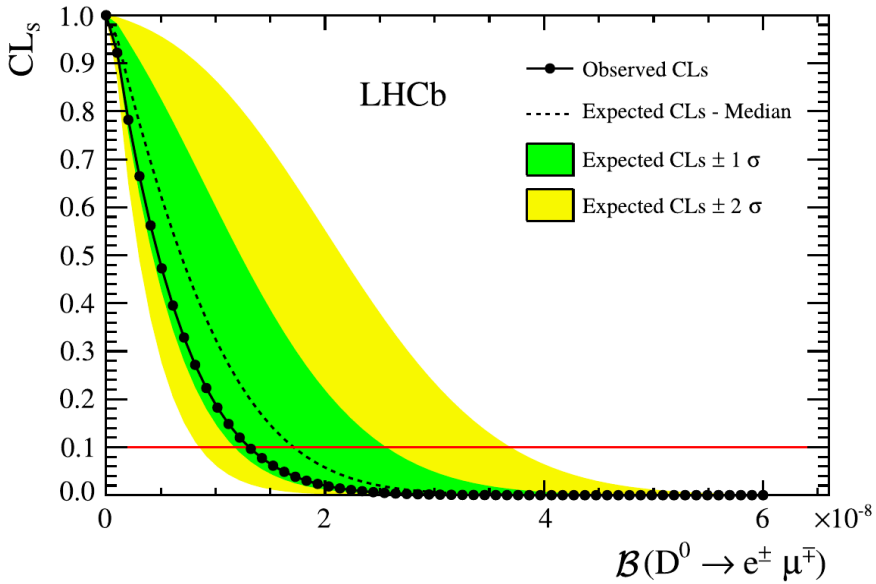


Search for the $D^0 \to e^+\mu^-$ decay [PLB 754 (2016) 167]





No evidence seen



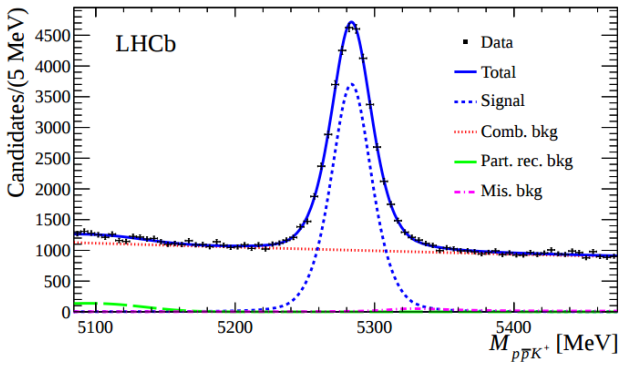
New world best limit

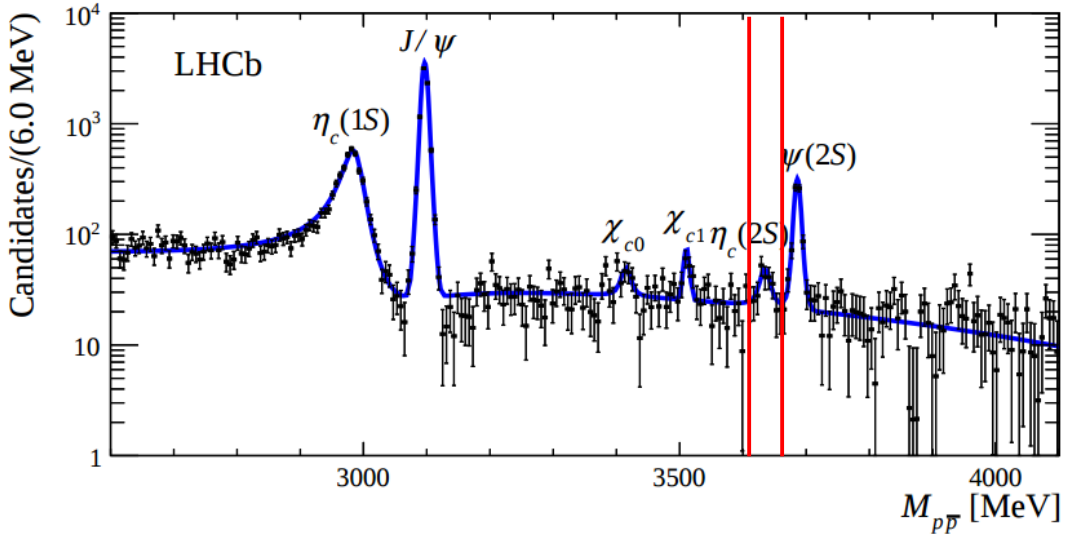
$$BF(D^0 \to e\mu) < 1.3(1.6) \times 10^{-8}$$

at 90(95)%CL

Observation of $\eta_c(2S) \to p\bar{p}$ and search for $X(3872) \to p\bar{p}$ decays arXiv:1607.06446

- Study of $p\bar{p}$ mass spectrum in $B^{\pm} \to p\bar{p}K^{\pm}$ decays (Run1 data, $3\,\mathrm{fb}^{-1}$)





- First observation of $\eta(2S) \to p\bar{p}$ at 6 σ
- No evidence for $\psi(3770) \to p\bar{p}$ and $X(3872) \to p\bar{p}$

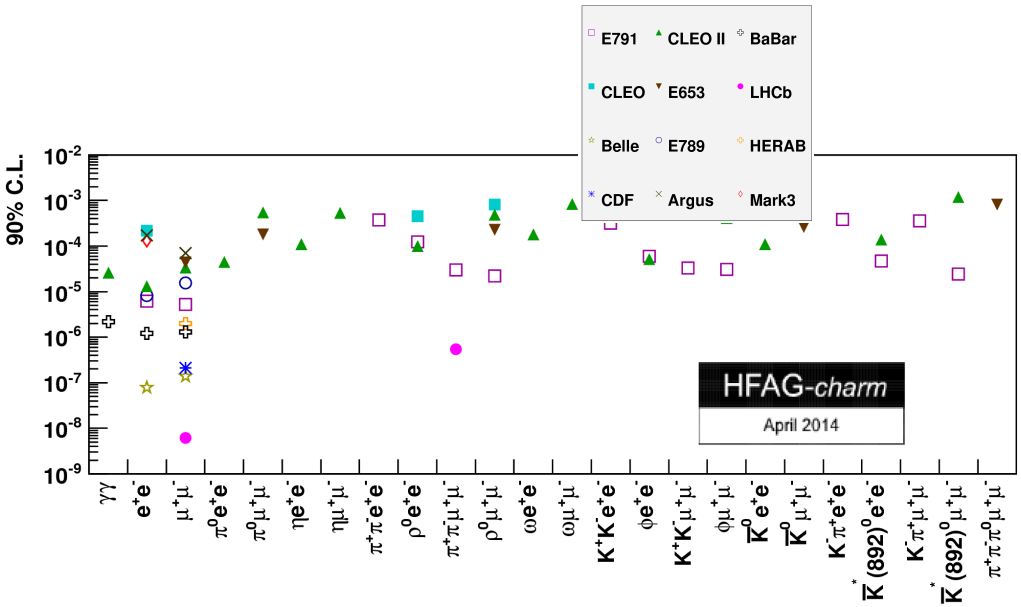
What is coming

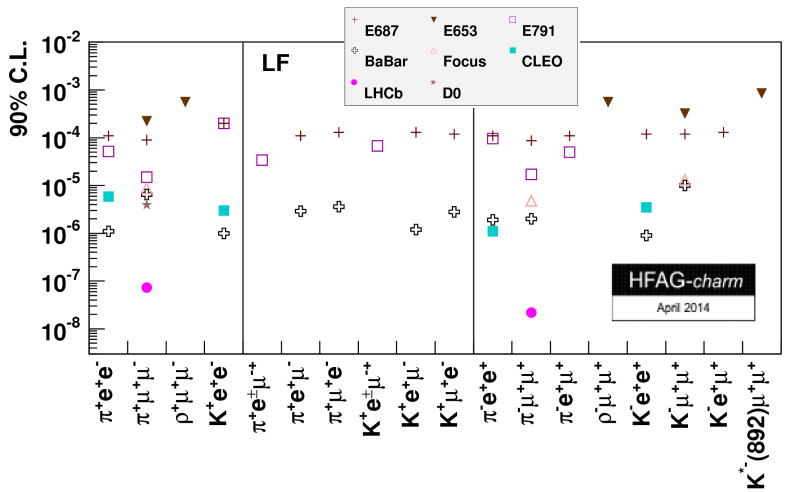
- Short term
  - Updated $D^0 \to \mu\mu$ analysis exploiting all Run1 statistics
  - Study of complete set of $D^+_{(s)} \to hll$ and $D^0 \to hhll$ decays with Run1+Run2 data
- What can be possible in Run3 an beyond?
  - Reach SM predictions for some modes
  - Combine constraints for all charm rare decays
  - Measure asymmetries (A_{FB}, A_{CP}, ...), some predictions (assuming the same efficiency and signal-to-background ratio):

Mode	Run II	Upgrade
$D^+ \to \pi^+\mu^+\mu^-$	0.6%(30K events)	0.2%(300K events)
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	3%(1500 events)	1%(15K events)
$D^0 \to K^-\pi^+\mu^+\mu^-$	1%(10K events)	0.3%(100K events)
$D^0 \to K^+\pi^-\mu^+\mu^-$	40%(30 events)	12%(300 events)
$D^0 \to K^+K^-\mu^+\mu^-$	11%(150 events)	4%(1500 events)

Conclusions

- Very active rare charm program at LHCb
- Almost every measurement is a world's best





- Even more interesting in the Run3, when the SM could be reached and more observables can be accessed

Backups

Projections for limits

- LHCb Run II: $8 fb^{-1}$, $\sqrt{s} = 13 TeV$
- LHCb Upgrade: $50 fb^{-1}$, $\sqrt{s} = 14 TeV$

Predictions on branching fractions's upper limits (assuming the same efficiency and S/B)

Mode	Run I	Run II	Upgrade
$D^0 \to hh'\mu^+\mu^-$	few 10^{-7}	fewer 10^{-7}	10^{-8}
$D^0 \to \mu^+\mu^-$	few 10^{-9}	fewer 10^{-9}	10^{-10}
$D^+ \to \pi^+\mu^+\mu^-$	few 10^{-8}	fewer 10^{-8}	10^{-9}
$D_s^+ \to K^+\mu^+\mu^-$	few 10^{-7}	fewer 10^{-7}	10^{-8}
$\Lambda \to p\mu\mu$	few 10^{-7}	fewer 10^{-7}	10^{-8}
$D^0 \to e\mu$	few 10^{-8}	fewer 10^{-8}	10^{-9}

Search for the $D^0 \to \pi^+\pi^-\mu^+\mu^-$ decay [PLB 728 (2014) 234-243]