Search for CP violation in charm decays at LHCb

Focus on the $D^+ \to K^- K^+ \pi^+$ channel

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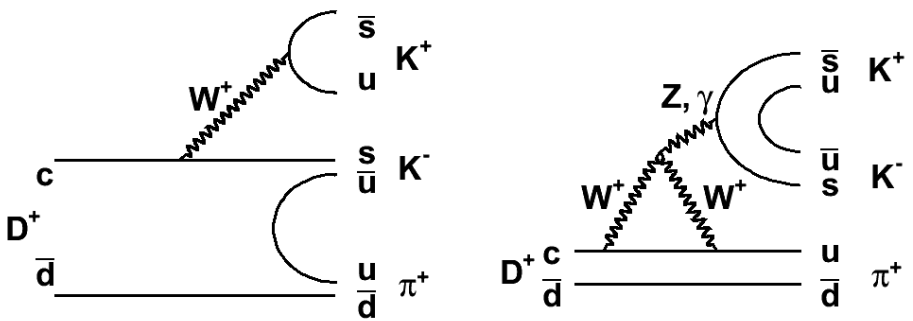
Introduction: CP violation in charm

CP violation in charm is only possible in the Standard Model in singly Cabibbo suppressed D decays



[1] PRL **108** 111602 (2012)

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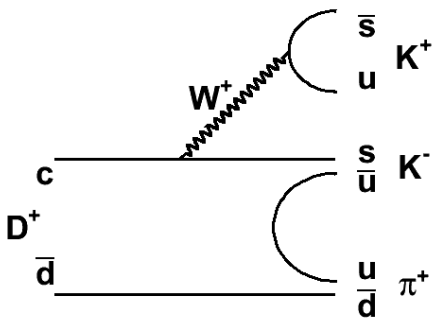

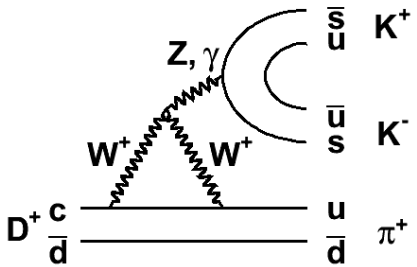

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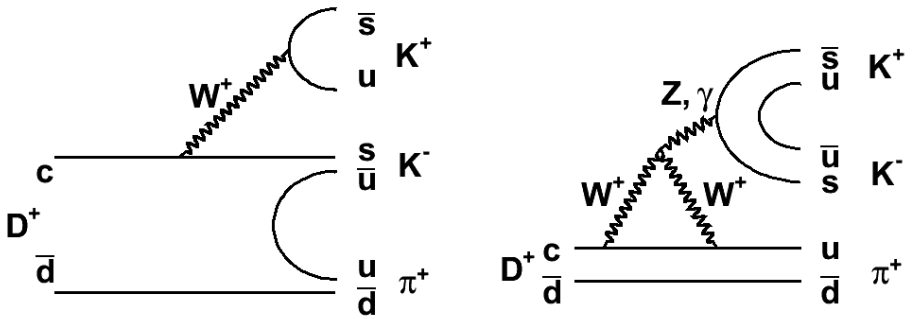

- CP violation (CPV) arises when tree and penguin amplitudes contribute to the same final state with different relative weak and strong phases.
- LHCb recently searched for a difference between the CP asymmetries of $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ and found evidence of CPV at the 3.5σ level[1], and CDF now have a similar result
- This can be explained within the Standard Model, but only just.
- Today I focus on an earlier search at LHCb using the 2010 dataset, which did not find evidence for CPV but has potential to do so in future.

[1] PRL **108** 111602 (2012)

Introduction: multibody decays at LHCb

Search for CP violation in $D^+ \to K^-K^+\pi^+$

- Three-body D decays are dominated by intermediate resonances.
- Interference between resonances with non-zero relative weak and strong phases leads to $\mathcal{CP}$ violation in a region of the Dalitz plot.
- The $\mathcal{CP}$ violation would be observed as a localised asymmetry between the numbers of D^+ and D^- decays.

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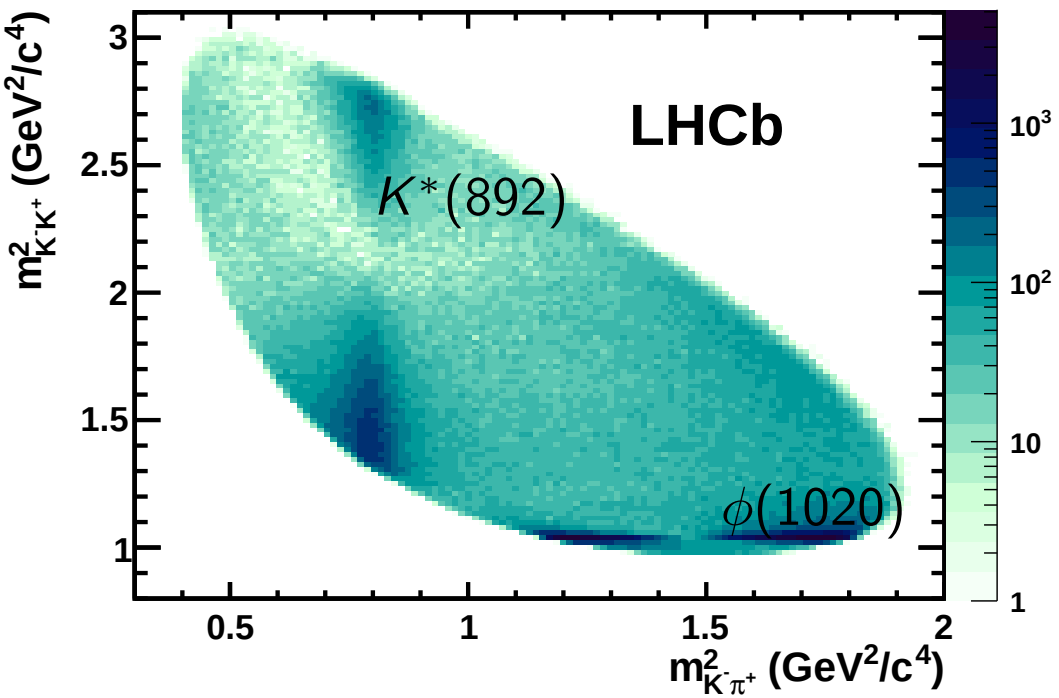

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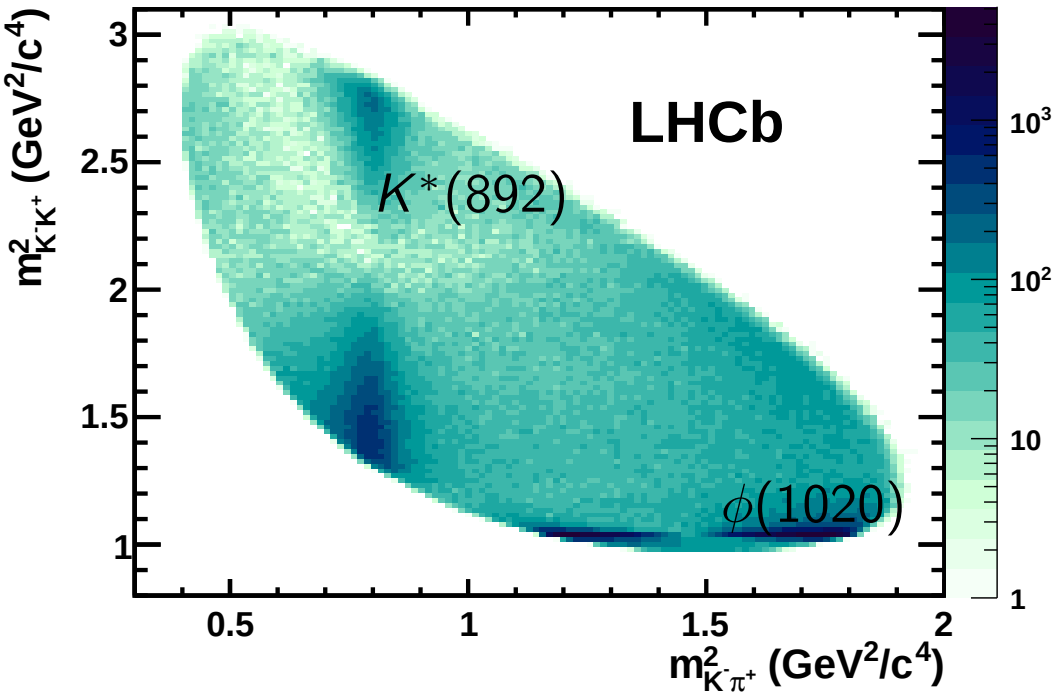


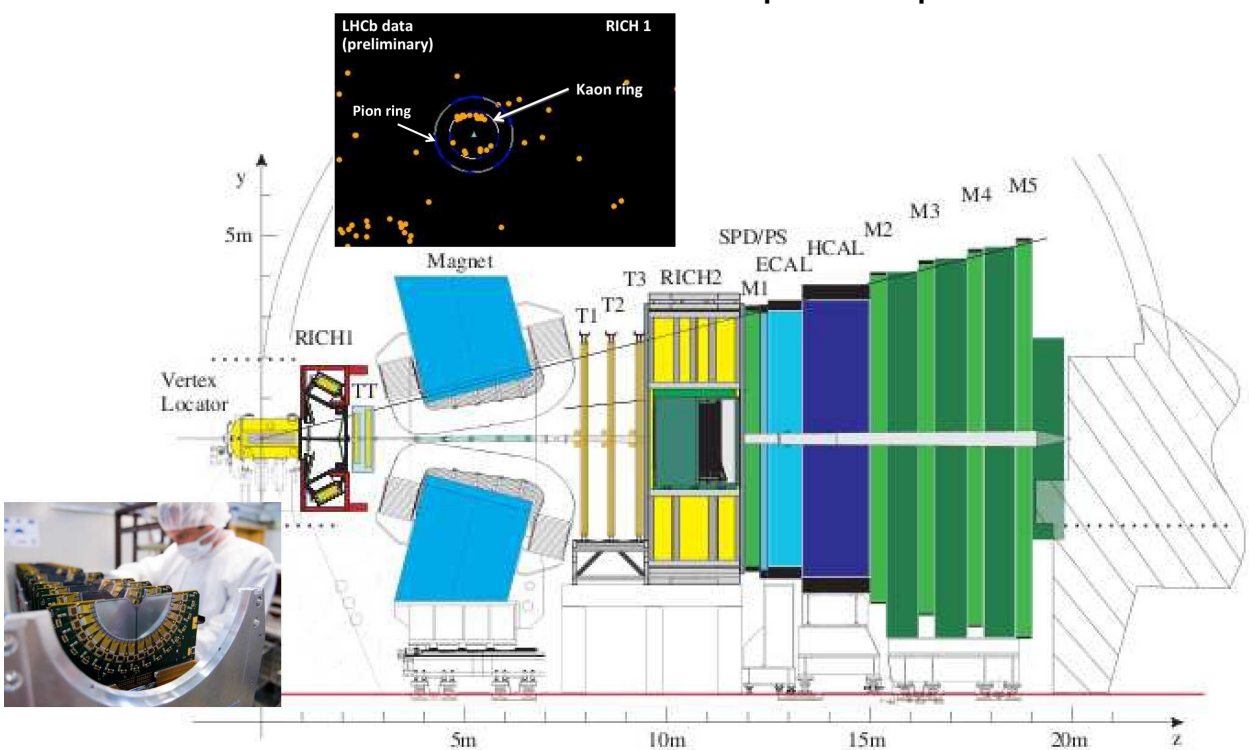
- This decay is studied with 35pb^{-1} of data taken in 2010[a]
- This is 20 times more data than was used in previous analyses at CLEO-c
- We now have 1fb^{-1} of data on tape

[a] PRD **84**, 112008 (2011)

The LHCb experiment

LHCb is a forward spectrometer for flavour physics at the LHC

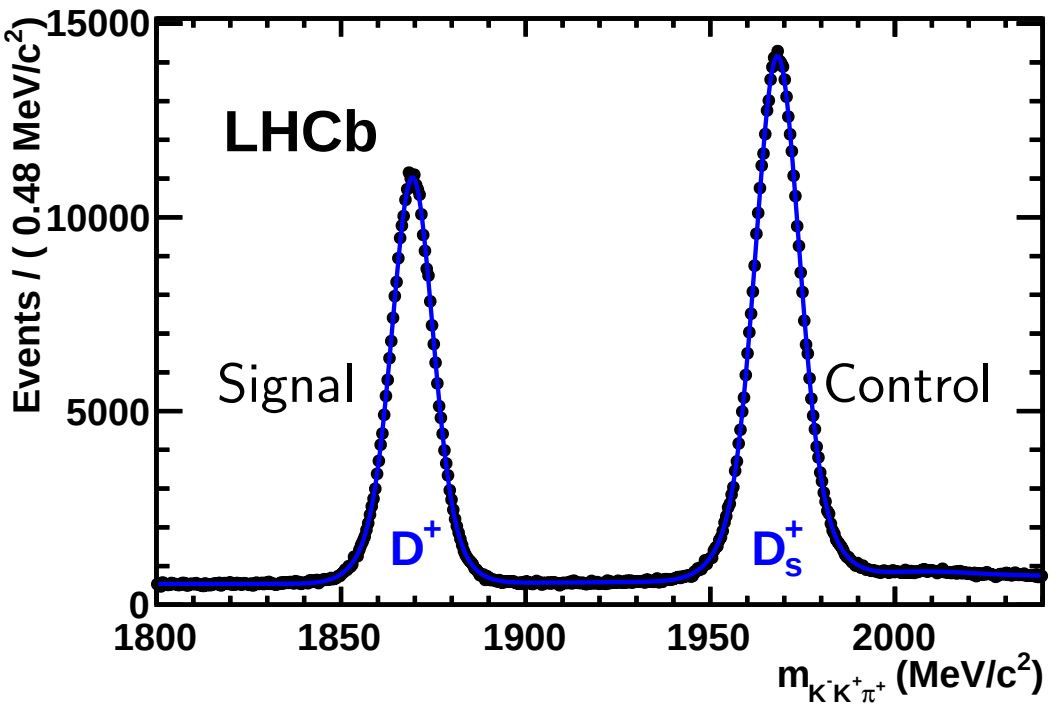
- b and c cross sections peak at high rapidity
- High precision silicon strip detector 7mm from the LHC beams (the VELO) provides very precise tracking and vertexing
  - This allows us to separate D's that are produced from B decays, and those which come from the proton-proton collision directly



- Two RICH detectors distinguish kaons from pions and protons
  - This allows us to separate Cabibbo-suppressed decays from their more abundant Cabibbo-favoured cousins

Selecting the signal

- Thanks to the high performance of the LHCb detector, clean signals are easy to select with cuts on simple kinematic variables like transverse momentum, impact parameter, etc.
- However it is important to maintain a relatively uniform efficiency across the Dalitz plot to maximise the sensitivity to CPV



- We have around 370,000 signal $D^{\pm}$ decays with around 90% purity
- The Cabibbo-favoured $D_s^+ \to K^-K^+\pi^+$ is an ideal control channel - more on this later

Analysis strategy

Search for CP violation in $D^+ \to K^-K^+\pi^+$

- To search for charge asymmetries, the Dalitz plot is binned and for each bin a local $\mathcal{CP}$ asymmetry variable is defined[2],

$$\mathcal{S}^i_{CP} = \frac{N^i(D^+) - N^i(D^-)}{\sqrt{N^i(D^+) + N^i(D^-)}} \tag{1}$$

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- In order to cancel the effect of production or detection (and $\mathcal{CP}$) asymmetries that are constant across the Dalitz plot, we introduce the ratio of the overall D^+ and D^- yields, α:

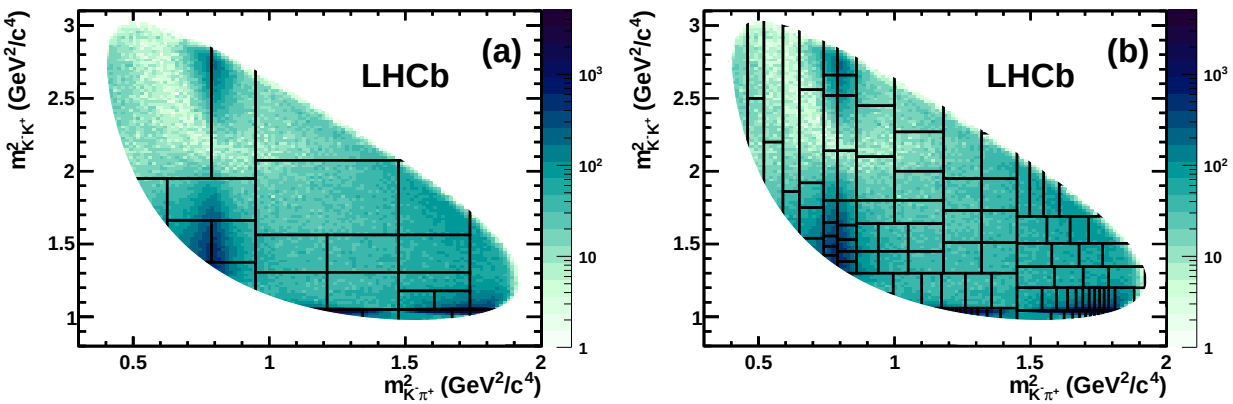
$$\mathcal{S}^i_{CP} = \frac{N^i(D^+) - \alpha N^i(D^-)}{\sqrt{N^i(D^+) + \alpha^2 N^i(D^-)}}\,, \qquad \alpha = \frac{N_{\text{tot}}(D^+)}{N_{\text{tot}}(D^-)}, \tag{2}$$

- A p-value for consistency with no $\mathcal{CP}$ violation in the Dalitz plot is generated from a χ^2/ndf, $\chi^2 = \sum(\mathcal{S}^i_{CP})^2/(N_{bins} - 1)$

Sensitivity studies

Toy MC studies performed with CLEO-c amplitude model[2]:

- To check we don't get false positive signals where no CPV exists
- To get an idea of the sensitivity to foreseeable types of CPV
- To guide us in developing "adaptive" binning schemes for the Dalitz plot (though we also use simple grids of same-sized "uniform" bins)



[2] PRD **78** 072003 (2008)

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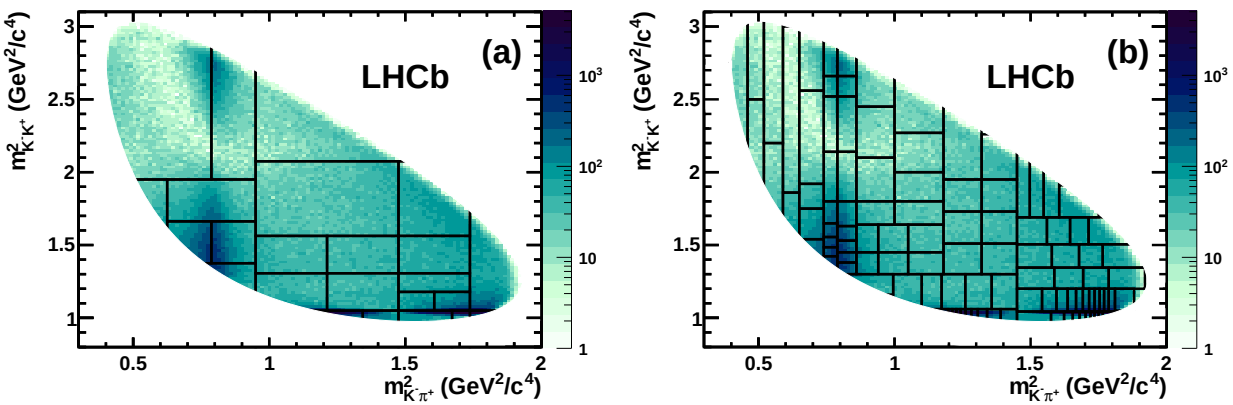


- Models work as expected, and suggest we would observe, with 2010 data, a CP-violating phase in the $\phi(1020)$ of 5° at the 3σ C.L. with approximately 90% probability
- Similarly, we're sensitive to about 11% CPV in $\kappa(800)$ amplitude

[2] PRD **78** 072003 (2008)

Control modes and related checks

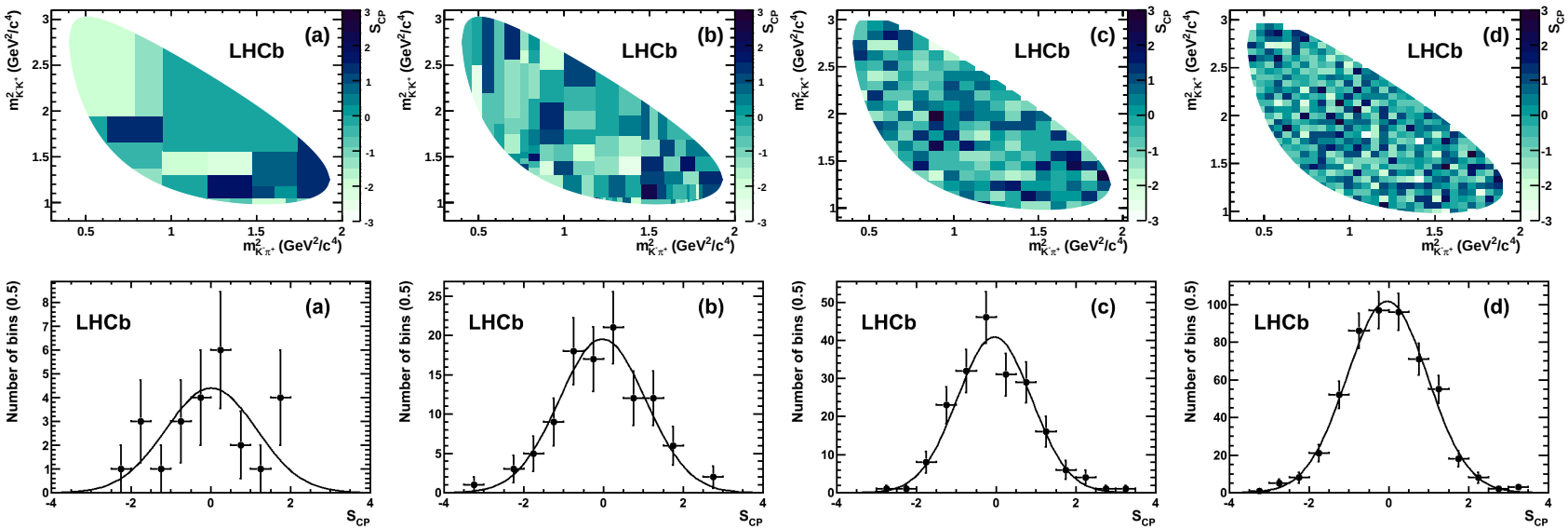
We checked that we are not sensitive to asymmetries due to (for example) detector effects or backgrounds

- In principle, momentum-dependent material interactions or acceptance effects could cause charge asymmetries which vary across the Dalitz plot
- In the control modes $D^+ \to K^-\pi^+\pi^+$ and $D_s^+ \to K^-K^+\pi^+$, and in all mass sidebands, no CPV is expected
- No significant asymmetries are seen

Results

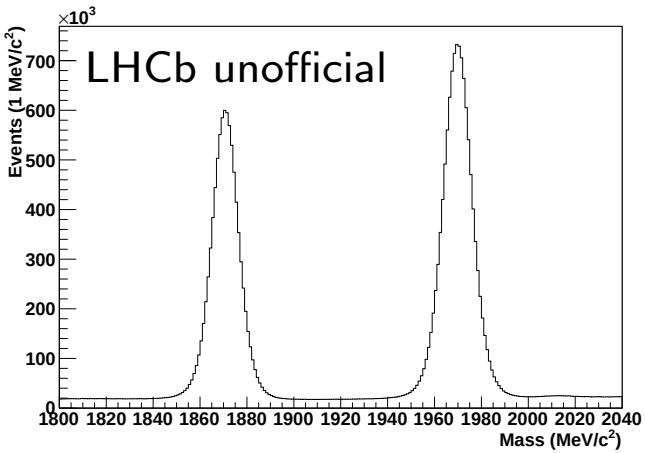
We observe no evidence of CPV in this decay

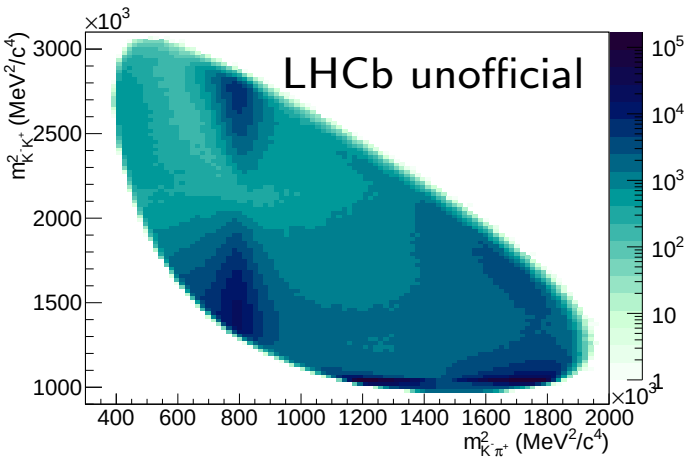
Binning	χ^2/ndf	p-value (%)
(a) Adaptive I	32.0/24	12.7
(b) Adaptive II	123.4/105	10.6
(c) Uniform I	191.3/198	82.1
(d) Uniform II	519.5/529	60.5



Outlook

There is strong motivation to update this measurement with the much larger 2011 dataset (with ~ 8 million signal decays)





- The technique can also be applied to, for example, $D^+ \to \pi^-\pi^+\pi^+$.
  - In this channel the detector asymmetries are simpler (for example, we do not require the RICH detectors)
- Alternative strategies are also under study: can perform an unbinned search by summing nearest-neighbour points[3]
- Lastly, it is possible to look in a particular part of the Dalitz plot, e.g. the ϕ resonance, and this also allows one to cancel detector effects

[3] PRD **84**, 054015 (2011)