Observation of the rare decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$

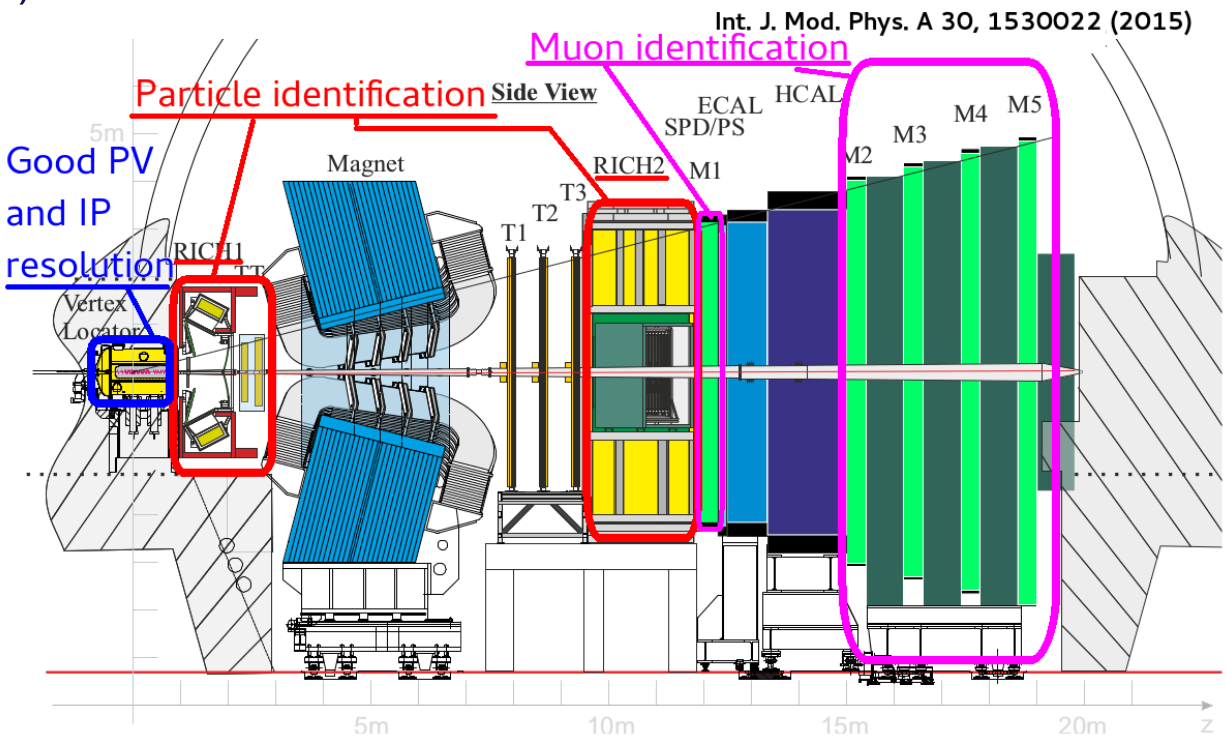
Eluned Smith[1] on behalf of the LHCb collaboration

[1]RWTH Aachen

Les Rencontres de Physique de la Vallée d'Aoste 5-11 March 2017

The LHCb detector

The LHCb detector is a single arm spectrometer which covers the forward region ($2<\eta<5$) at the LHC.



Δ p/p $\sim$ 0.4% at 5 GeV, σ_{IP} = 20 μm for high p_T tracks.

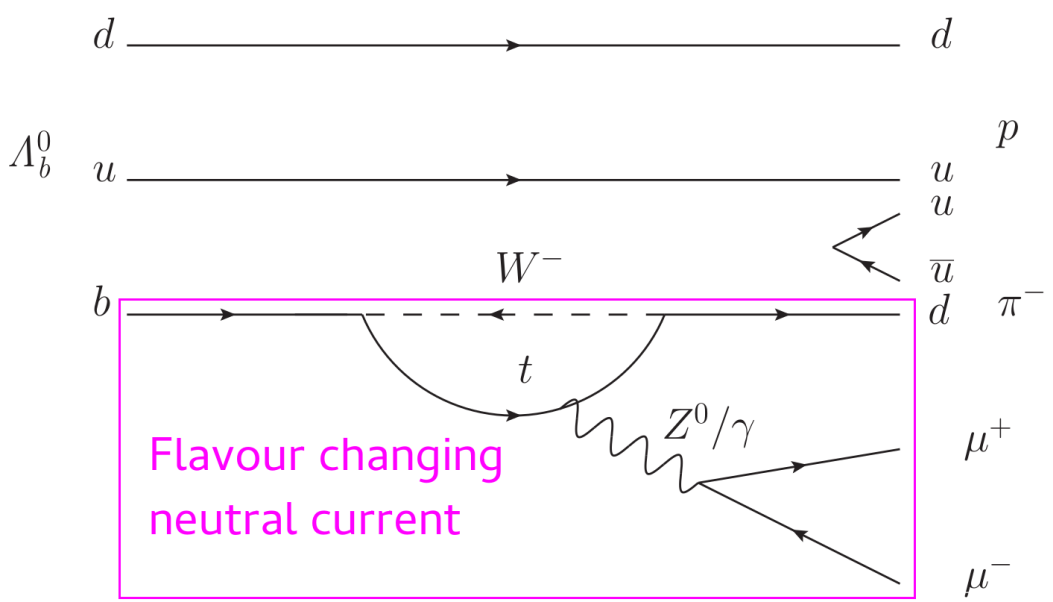
π/K separation: ϵ_K ~90%, 5% $\pi \rightarrow K$ mis-id.

π/μ separation: ϵ_μ ~97%, 1-3% $\pi \rightarrow \mu$ mis-id.

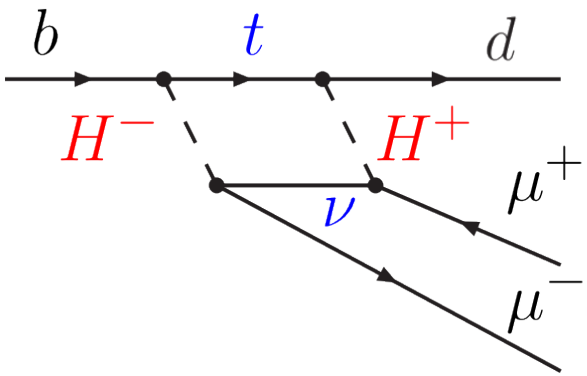
$\Lambda_b^0 \to p\pi^-\mu^+\mu^-$: FCNC processes

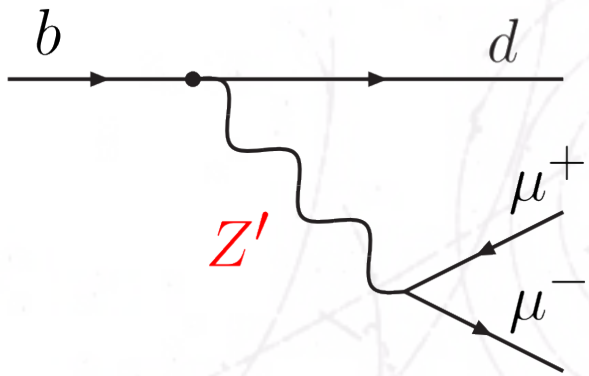
The decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$, where the muons do not originate from a resonance, is mediated via Flavour Changing Neutral Currents (FCNC).

$\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ is both loop and Cabibbo suppressed $\to$ very rare ($\mathcal{B} \sim 10^{-8}$)



Rare decay: decay rate could be sensitive to new particles in FCNC's



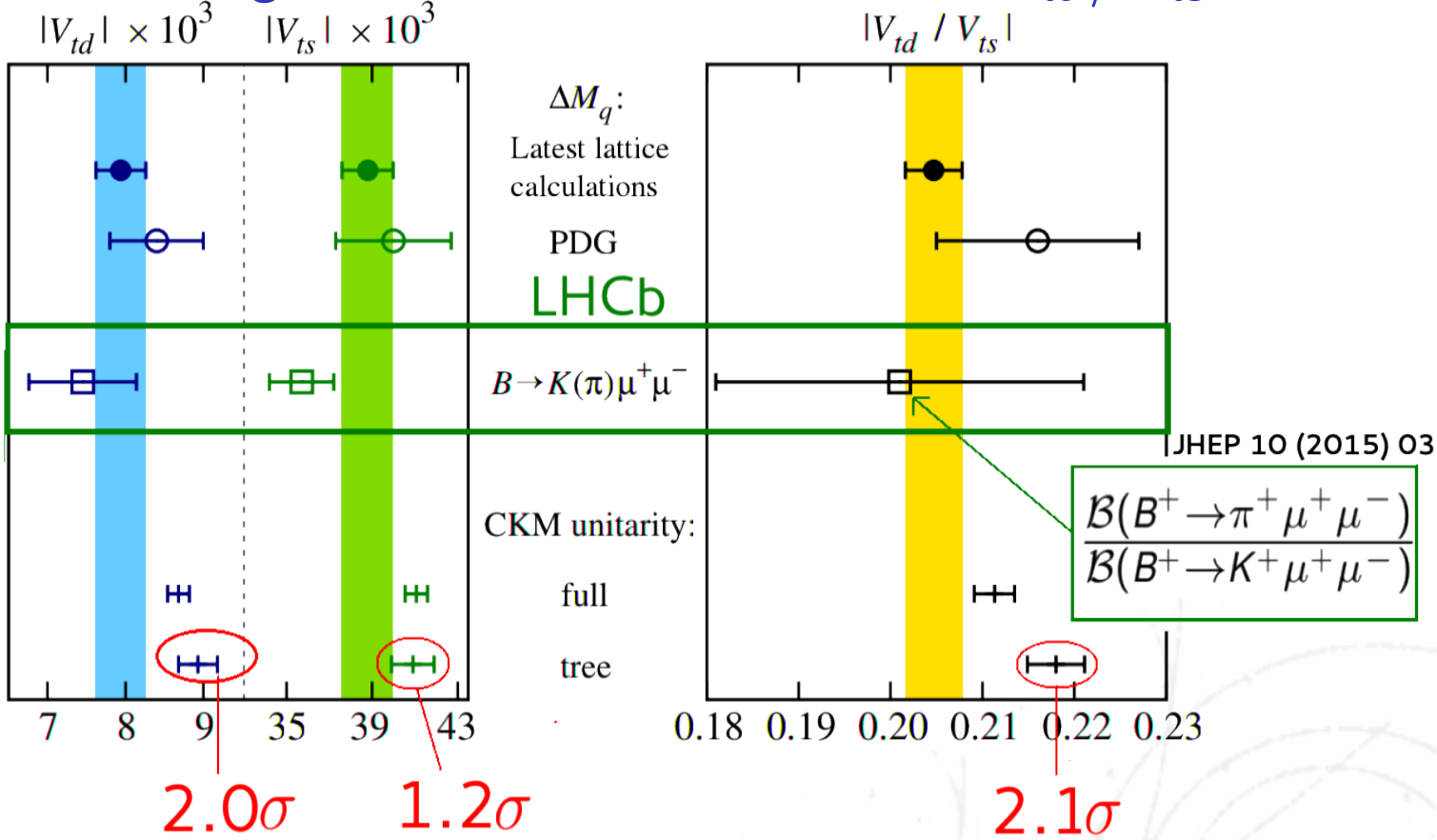


The minimal flavour violation hypothesis

- The excellent agreement with theory of flavour measurements places stringent constraints on the mass scale, Λ, of new physics $\rightarrow$ if new physics is assumed to have a generic flavour structure of $\mathcal{O}(1) \rightarrow \Lambda$ as high as 10^4 TeV (Ann.Rev.Nucl.Part.Sci.60:355, 2010)
- The MFV hypothesis offers solution to this flavour problem:

  Assume NP flavour structure = SM flavour structure
- Comparing the CKM elements obtained via loop and tree level processes tests the MFV hypothesis.

Testing MFV using the CKM element ratio V_{td}/V_{ts}



Phys. Rev. D 93, 113016 (2016)

Measuring $\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)$ and combining with $\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-) \to$ measure V_{td}/V_{ts} via $\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-)}$

Analysis strategy

$$\mathcal{B}_{\Lambda_b^0 \to p\pi^-\mu^+\mu^-} = \mathcal{B}_{\Lambda_b^0 \to J/\psi\, p\pi^-} \mathcal{B}_{J/\psi \to \mu^+\mu^-} \frac{N_{\Lambda_b^0 \to p\pi^-\mu^+\mu^-}}{N_{\Lambda_b^0 \to J/\psi\,(\to \mu^+\mu^-)p\pi^-}} \frac{\epsilon_{\Lambda_b^0 \to J/\psi\, p\pi^-}}{\epsilon_{\Lambda_b^0 \to p\pi^-\mu^+\mu^-}}$$

- Perform blind analysis using $3\,\text{fb}^{-1}$ of data collected by LHCb during 2011, 2012
- Measure the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ branching fraction relative to that of $\Lambda_b^0 \to J/\psi\ (\to \mu^+\mu^-)p\pi^-$.
- Remove background to fit for number of events in both channels.
- Use Monte Carlo to calculate efficiencies.

Background removal

- Background removed via
  - Selections in dimuon mass, q, to remove J/ψ and $\psi(2S)$ resonances.
  - Multivariant analysis techniques $\rightarrow$ BDT's used to reduce combinatorial and partially reconstructed backgrounds (e.g. $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow p\pi^+\pi^-)\mu\nu$).
  - Use of LHCb particle identification to reduce exclusive backgrounds such as $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$.
  - Selections optimised using the Punzi figure of merit (arXiv:physics/0308063)

Efficiency of selection

Number of background events

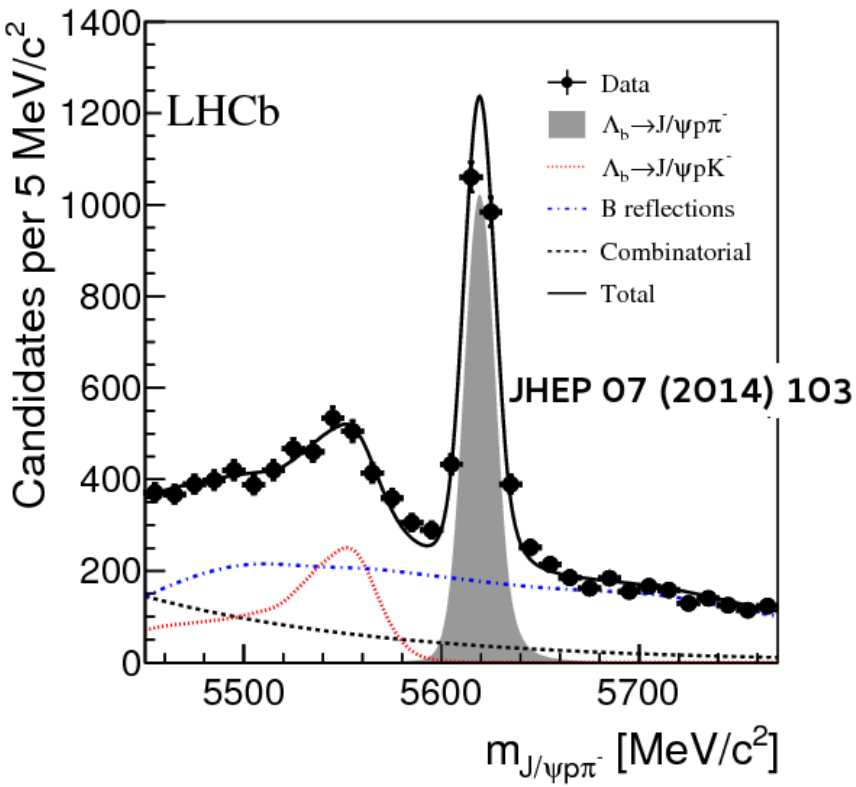
$$\mathrm{F.o.M} = \frac{\epsilon}{\sqrt{\sigma/2 + B}}$$

Expected significance

as no prediction for the SM branching fraction.

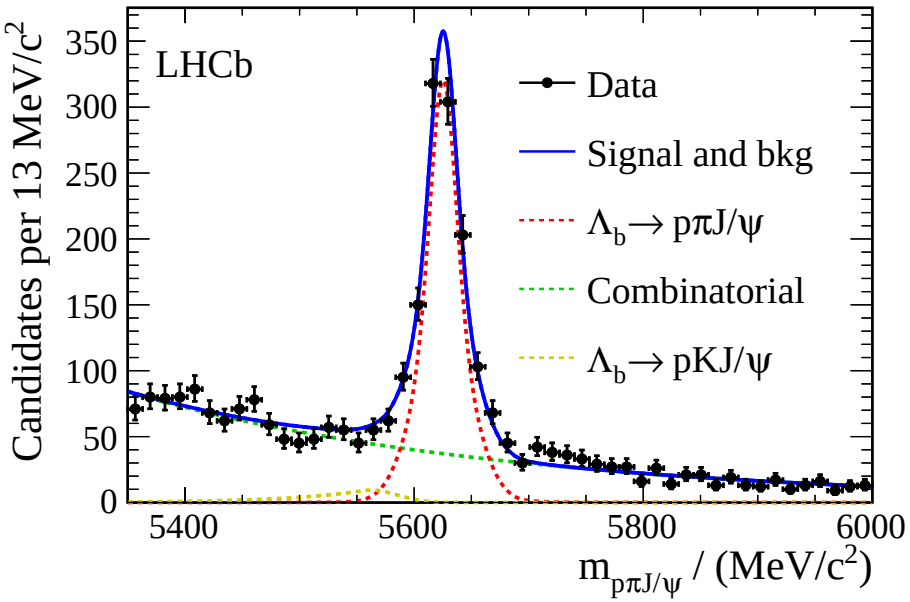
The normalisation channel

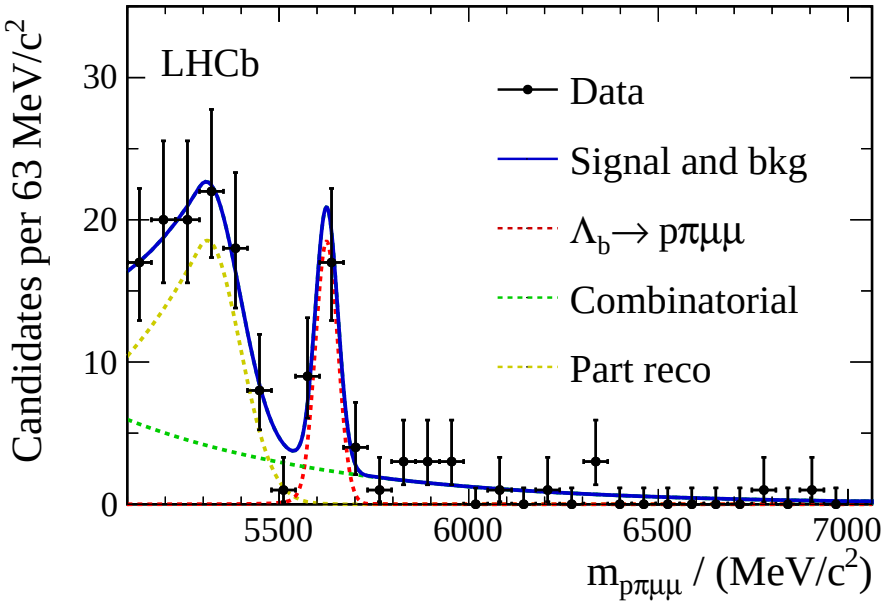
- $\Lambda_b^0 \to J/\psi\, p\pi^-$ was observed previously by LHCb with $\sim$ 2000 events
  (JHEP 07 (2014) 103)
- $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ and $\Lambda_b^0 \to J/\psi\, p\pi^-$ differ in their dimuon invariant mass spectrum, q.
- Relative efficiencies between the signal and normalisation channels are therefore calculated in bins of q^2.



Fit strategy

- Signal shape for $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ fixed from $\Lambda_b^0 \to J/\psi\, p\pi^-$ signal shape.
- Plots from arXiv:1701.08705

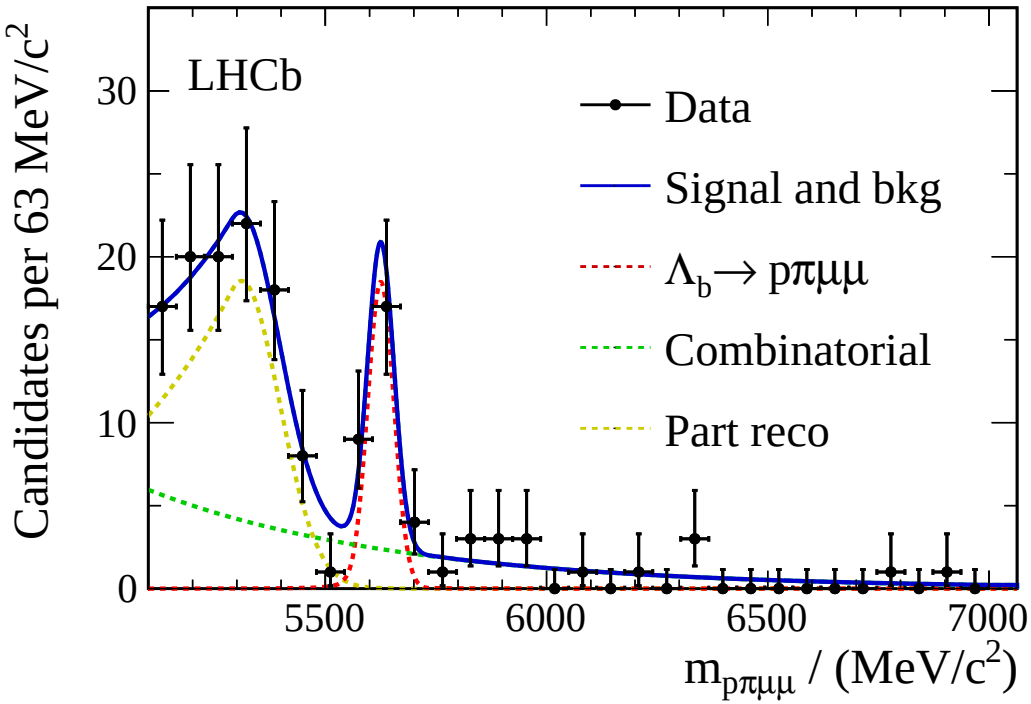




Background in $\Lambda_b^0 \to J/\psi\, p\pi^-$:
combinatorial (data),
$\Lambda_b^0 \to J/\psi\, p\,(K^- \to \pi^-)$ (sim.)

Background in $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$:
combinatorial (data),
partially reconstructed backgrounds (data).

Significance



- $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ observed with 5.5σ significance (plot from arXiv:1701.08705).
- First observation of a $b \to d$ transition in the baryon sector.

Final values

$$\mathcal{B}_{\Lambda_b^0\to p\pi^-\mu^+\mu^-} = \mathcal{B}_{\Lambda_b^0\to J/\psi\, p\pi^-}\,\mathcal{B}_{J/\psi\to\mu^+\mu^-}\,\frac{N_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}}{N_{\Lambda_b^0\to J/\psi(\to\mu^+\mu^-)p\pi^-}}\,\frac{\epsilon_{\Lambda_b^0\to J/\psi\, p\pi^-}}{\epsilon_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}}$$

$N_{\Lambda_b^0\to J/\psi(\to\mu^+\mu^-)p\pi^-}$	1017 ± 41
$N_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}$	22 ± 6
$\frac{\epsilon_{\Lambda_b^0\to J/\psi\, p\pi^-}}{\epsilon_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}}$	0.487 ± 0.022
$\mathcal{B}_{\Lambda_b^0\to J/\psi\, p\pi^-}$	$2.613 \pm 0.086 \pm 0.133^{+0.467}_{-0.370} \times 10^{-5}$
$\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0\to J/\psi\, p\pi^-)}$	$0.044 \pm 0.012 \pm 0.007$

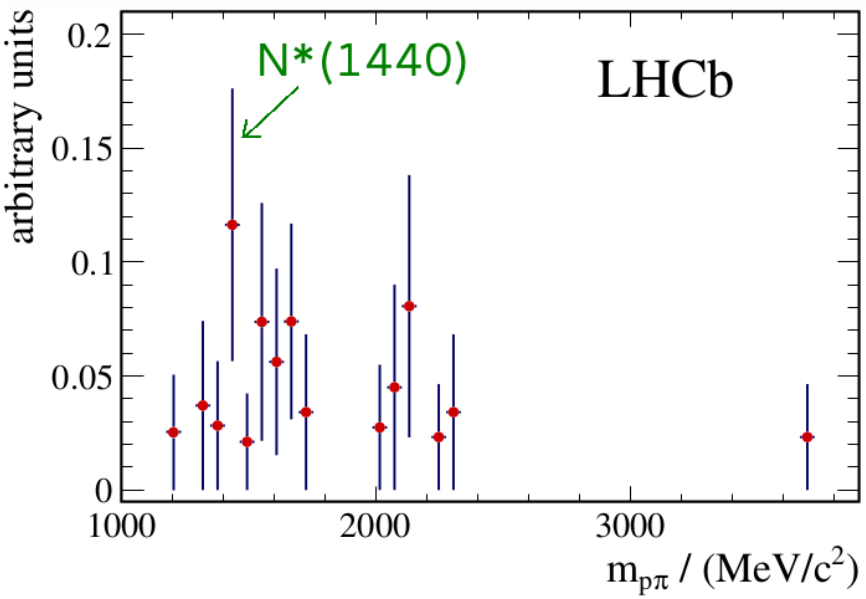
arXiv:1701.08705

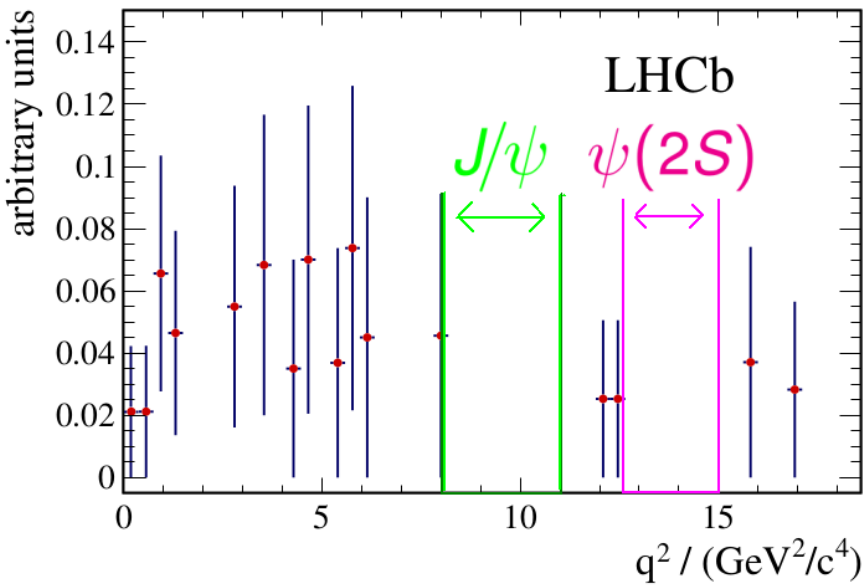
stat.

$$\mathcal{B}_{\Lambda_b^0\to p\pi^-\mu^+\mu^-} = (6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}$$

syst.

$m_{p\pi}$ and q^2 distributions





arXiv:1701.08705 - supplementary material

Efficiency-weighted distributions in $m_{p\pi}$ and q^2 for events in the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ signal region

Outlook

- This measurement of $\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)$ can be used to test the SM pending:
  - A prediction of $\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)$ by theorists
  - A measurement of $\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-)$ - this decay has been observed by LHCb (arXiv:1703.00256) and the branching fraction measurement is due to be published soon
  - The determination of the relevant form factors in the ratio $\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)}{\mathcal{B}\Lambda_b^0 \to pK^-\mu^+\mu^-}$ by theorists to extract V_{td}/V_{ts}

Conclusions

- First observation of a $b \to d$ transition in the baryon sector, via the mode $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$
- Branching fraction measured to be $(6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}$
- Plans to combine measurement with $\mathcal{B}(\Lambda_b^0 \to pK^-\mu^+\mu^-)$ to extract V_{td}/V_{ts} in the near future.

Back-up slides

Systematic uncertainties

Table 1: Summary of the systematic uncertainties on the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ branching fraction.

Source	Uncertainty (%)
Modelling of the q^2 distribution	7.9
Modelling of the $p\pi^-$ mass distribution	7.7
Effect of the partially reconstructed background fit shape	6.9
Choice of BDT efficiency proxy	5.6
Finite size of the simulated sample	4.4
Statistical uncertainty on $\Lambda_b^0 \to J/\psi\, p\pi^-$ yield	4.0
Trigger efficiency	3.4
Fit bias	2.2
$\Lambda_b^0 \to pK^-\mu^+\mu^-$ contamination	1.6
Simulation corrections	1.3
PID efficiency	1.0
Total	16.1

Comparision of $\Lambda_b^0 \to J/\psi\, p\pi^-$ from previous and current analysis