D decays at LHCb

The University of Manchester

Chris Burr, on behalf of the LHCb collaboration

18th September @ CKM 2018, Heidelberg

Outline

- Measurement of $D_s^{\pm}$ production asymmetry in pp collisions at √s=7 and 8 TeV [JHEP 08 (2018) 008]
- Measurement of angular and CP asymmetries in $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$ decays [PHYS. REV. LETT. 121 (2018) 091801]
- Measurement of the branching fractions of the decays $D^+ \to K^-K^+K^+$, $D^+ \to \pi^-\pi^+K^+$ and $D_s^+ \to \pi^-K^+K^+$ [LHCB-PAPER-2018-033] (in preparation)

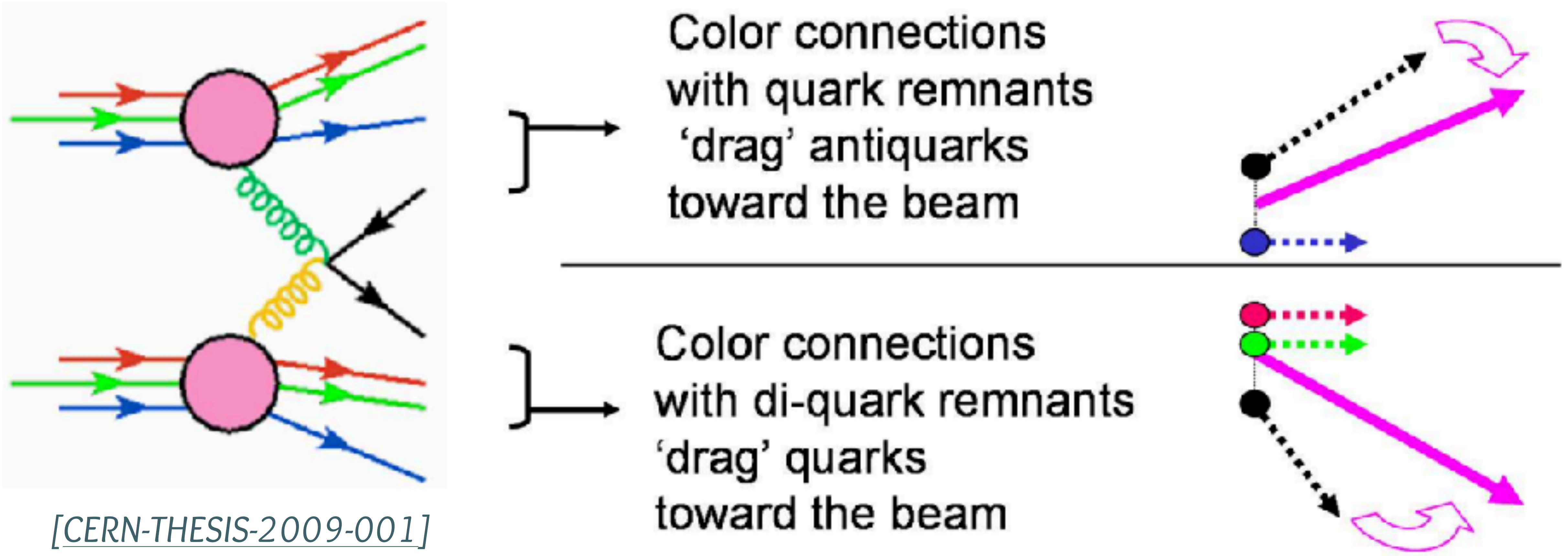
Brand New!

[JHEP 08 (2018) 008]

Measurement of $D_s^{\pm}$ production asymmetry in pp collisions at √s=7 and 8 TeV

Analysis overview

- Measure $D_s^\pm$ production asymmetry using $D_s^\pm \to (\phi \to K^+K^-)\,\pi^\pm$ decays
  - $2.9\text{x}10^6$ ($9.1\text{x}10^6$) signal decays from 1.0 fb^{-1} (2.0 fb^{-1}) taken in 2011 (2012) at √s = 7 TeV (8 TeV)
- Input for CP-violation studies and helps probe the production mechanisms
- $D_s^\pm$ system production asymmetry is not caused by valence quarks
  - Can be caused by beam drag:



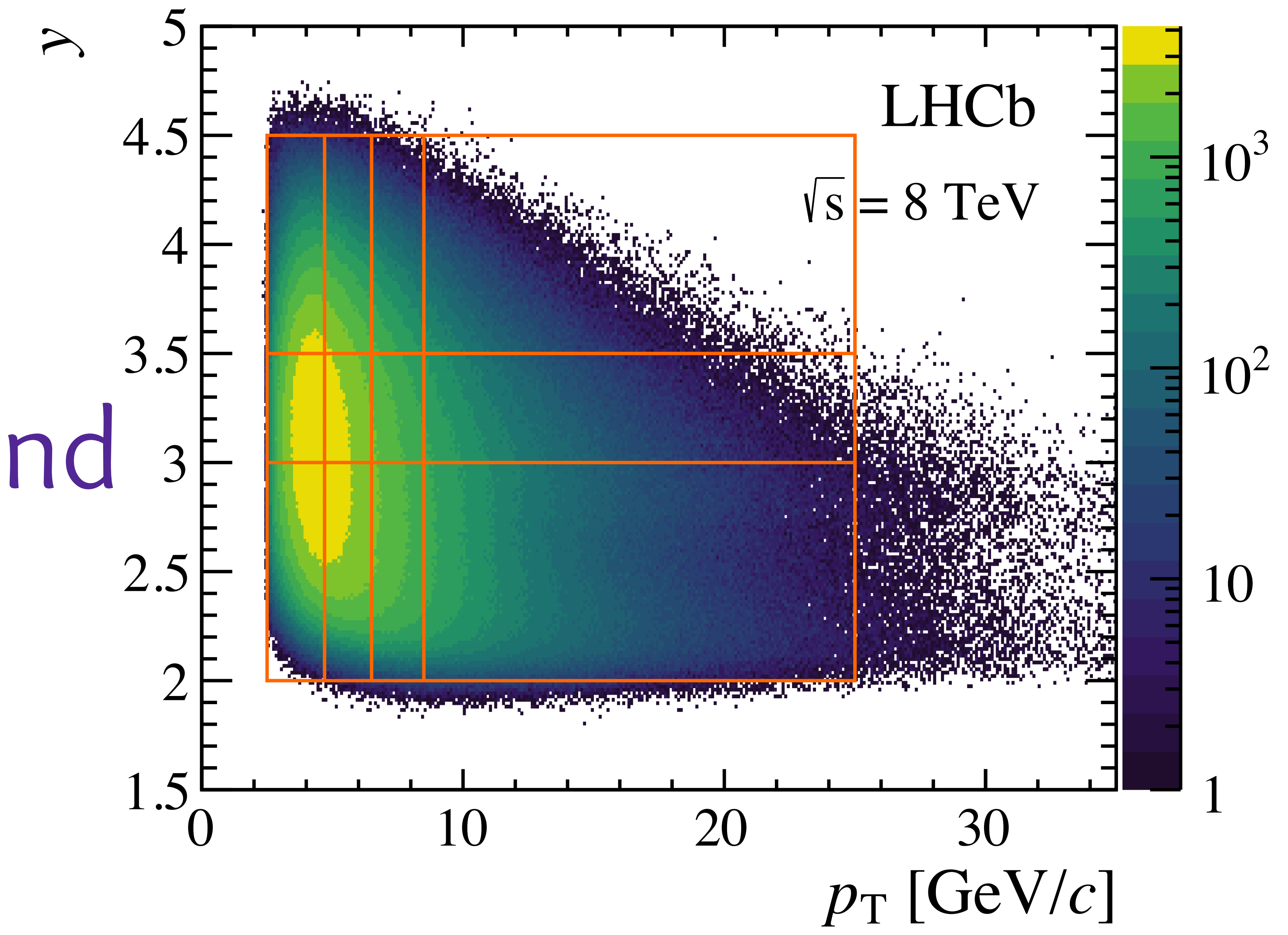
[CERN-THESIS-2009-001]

- Previous measurement using only 7 TeV data showed a small excess of D_s^-

Analysis details

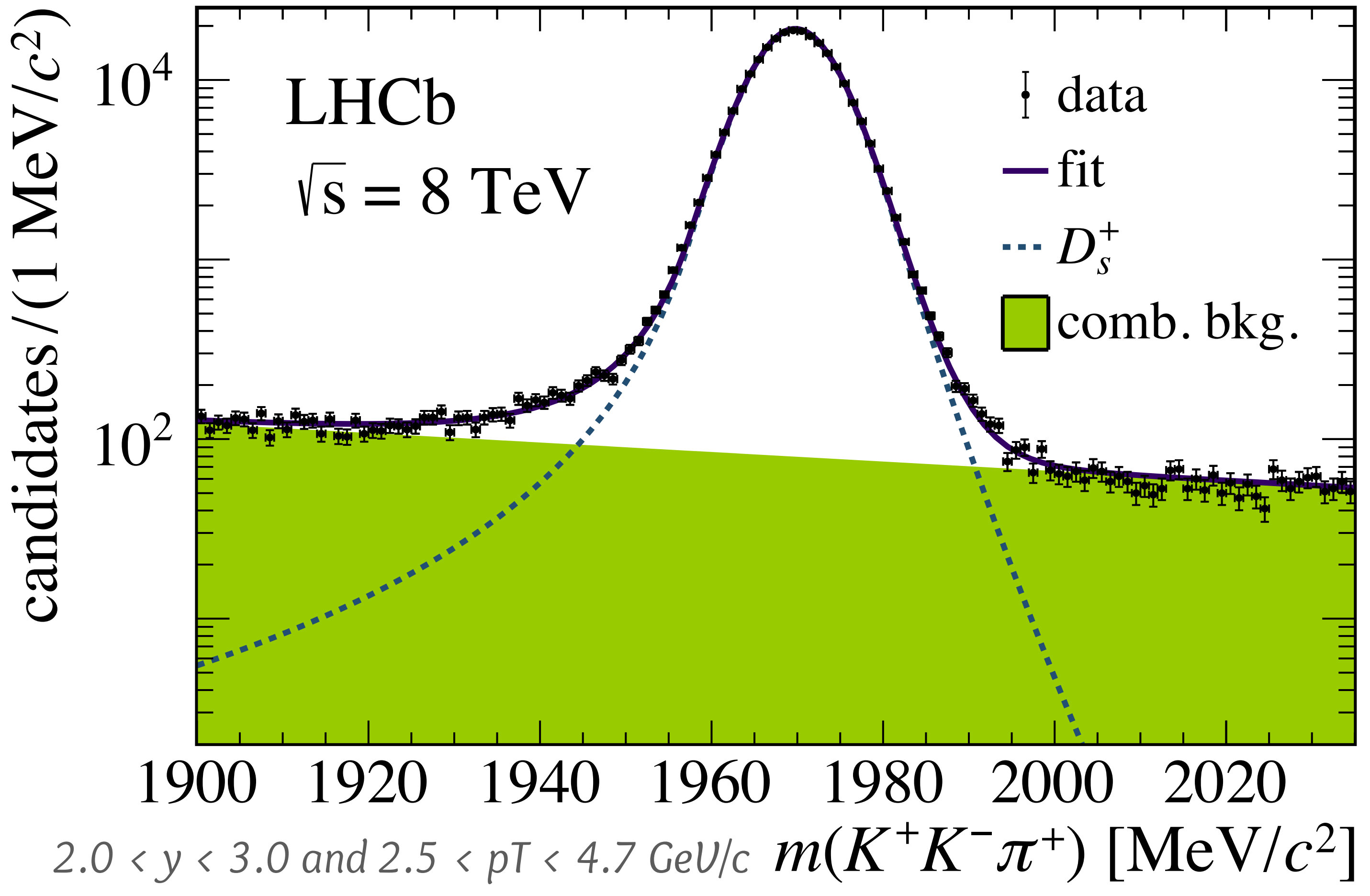
➤ Use four bins in p_T and three in rapidity, combine to give a total asymmetry

$$A_P\left(D_s^+\right) = \frac{1}{1 - f_{bkg}}\left(A_{raw} - A_D - f_{bkg}\, A_P(B)\right)$$

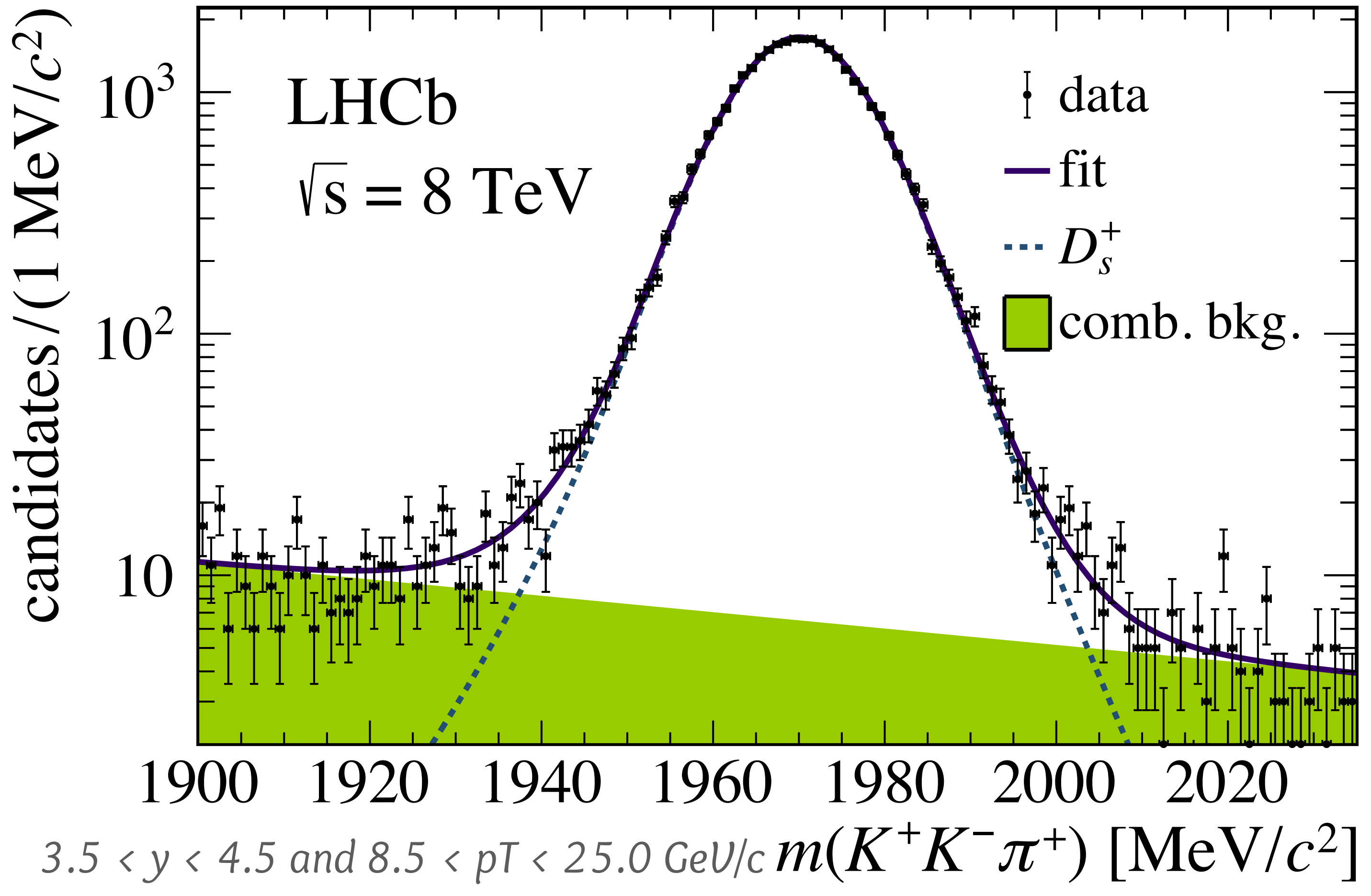


Distribution of signal candidates in the 8 TeV data with the kinematic binning overlaid

➤ Hypatia[1] function for signal on exponential background



2.0 < y < 3.0 and 2.5 < pT < 4.7 GeV/c



3.5 < y < 4.5 and 8.5 < pT < 25.0 GeV/c

Invariant mass distributions for the "down" magnet polarity with fit results overlaid

[1] 10.1016/j.nima.2014.06.081

[JHEP 08 (2018) 008]

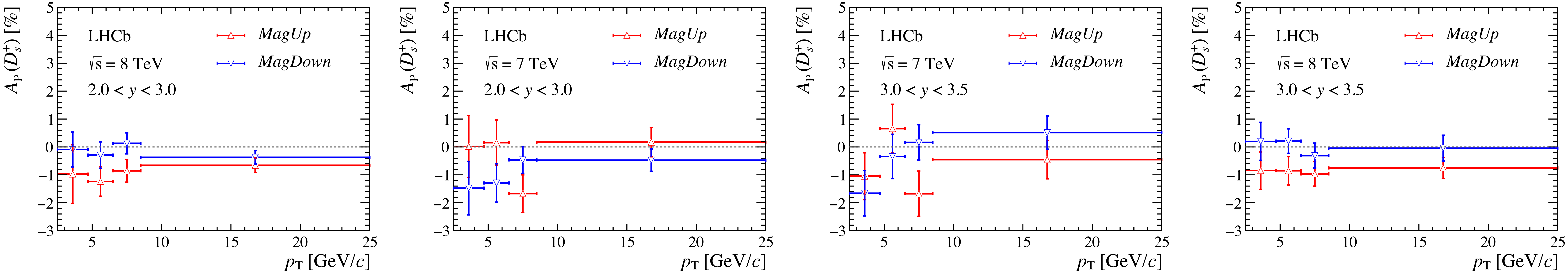
Asymmetry corrections

$$A_P\left(D_s^+\right) = \frac{1}{1 - f_{bkg}}\left(A_{raw} - A_D - f_{bkg}\, A_P(B)\right)$$

- $D_s^\pm$ from decays of b-hadrons
  - Estimated to be (4.12 ± 1.23)% of all signal candidates
  - Taken from LHCb production asymmetry measurements of b hadrons
  - Background asymmetry found to be small in comparison to the precision of this measurement

- Detection asymmetries taken from separate control samples
  - Tracking, particle identification and trigger asymmetries contribute

- All bins agree to within 2σ between the “up” and “down” magnet polarity



- Combine both magnet polarities to give 12 binned results:

	y		
p_{T} [GeV/c]	2.0 – 3.0	3.0 – 3.5	3.5 – 4.5
2.5 – 4.7	$-0.59 \pm 0.40 \pm 0.32$	$-0.34 \pm 0.37 \pm 0.13$	$-0.45 \pm 0.39 \pm 0.14$
4.7 – 6.5	$-0.73 \pm 0.29 \pm 0.27$	$-0.15 \pm 0.31 \pm 0.10$	$-0.73 \pm 0.30 \pm 0.13$
6.5 – 8.5	$-0.32 \pm 0.27 \pm 0.06$	$-0.49 \pm 0.31 \pm 0.10$	$-0.40 \pm 0.36 \pm 0.17$
8.5 – 25.0	$-0.48 \pm 0.17 \pm 0.08$	$-0.32 \pm 0.26 \pm 0.10$	$-0.74 \pm 0.39 \pm 0.09$

- Agrees with the $K^*(892)^0$ and non-resonant Dalitz regions

- Combining all 12 p_T/y bins results gives a total asymmetry

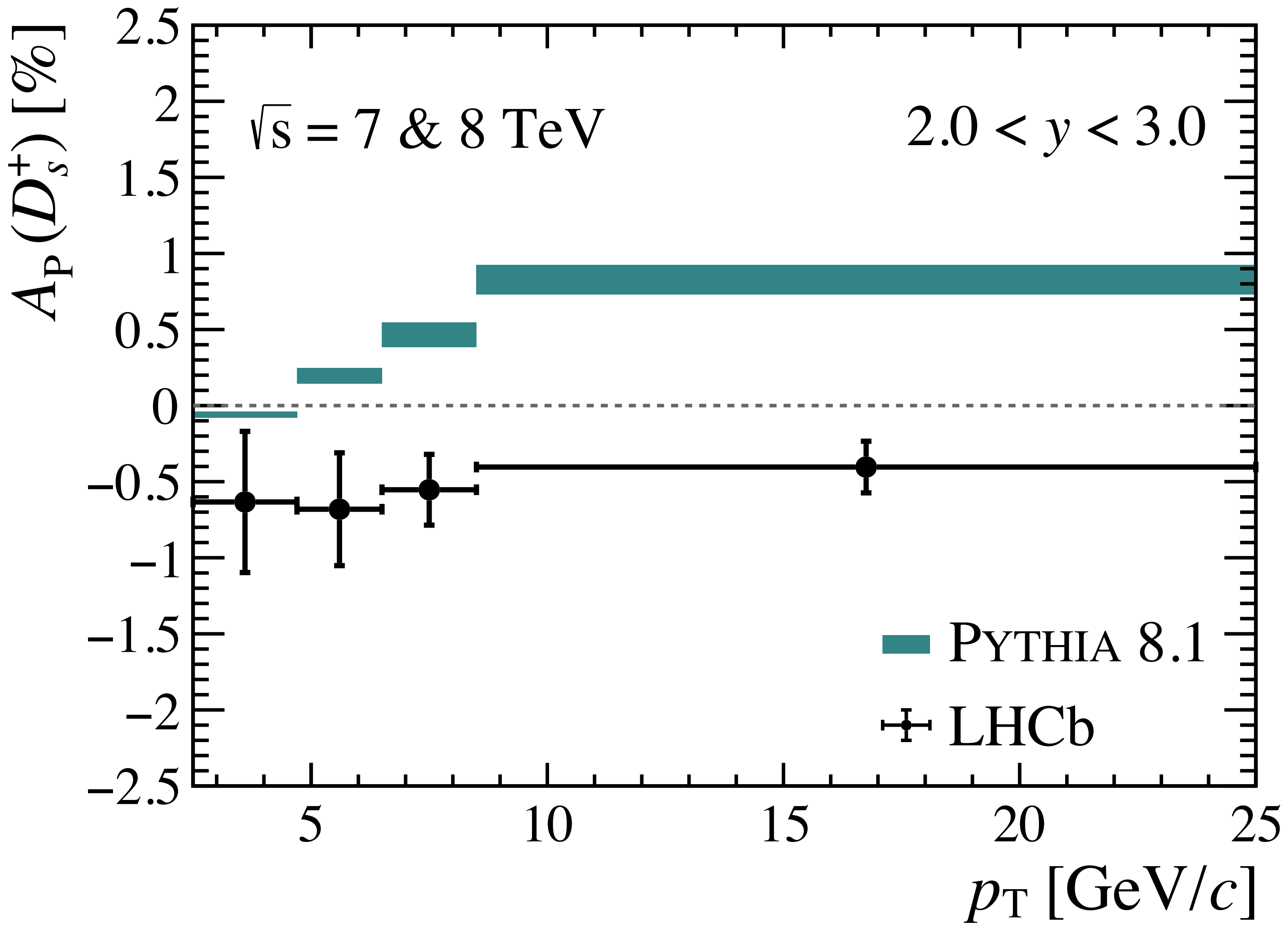
$$A_P\left(D_s^+\right) = \left(-0.52 \pm 0.13 \pm 0.10\right)\,\%$$

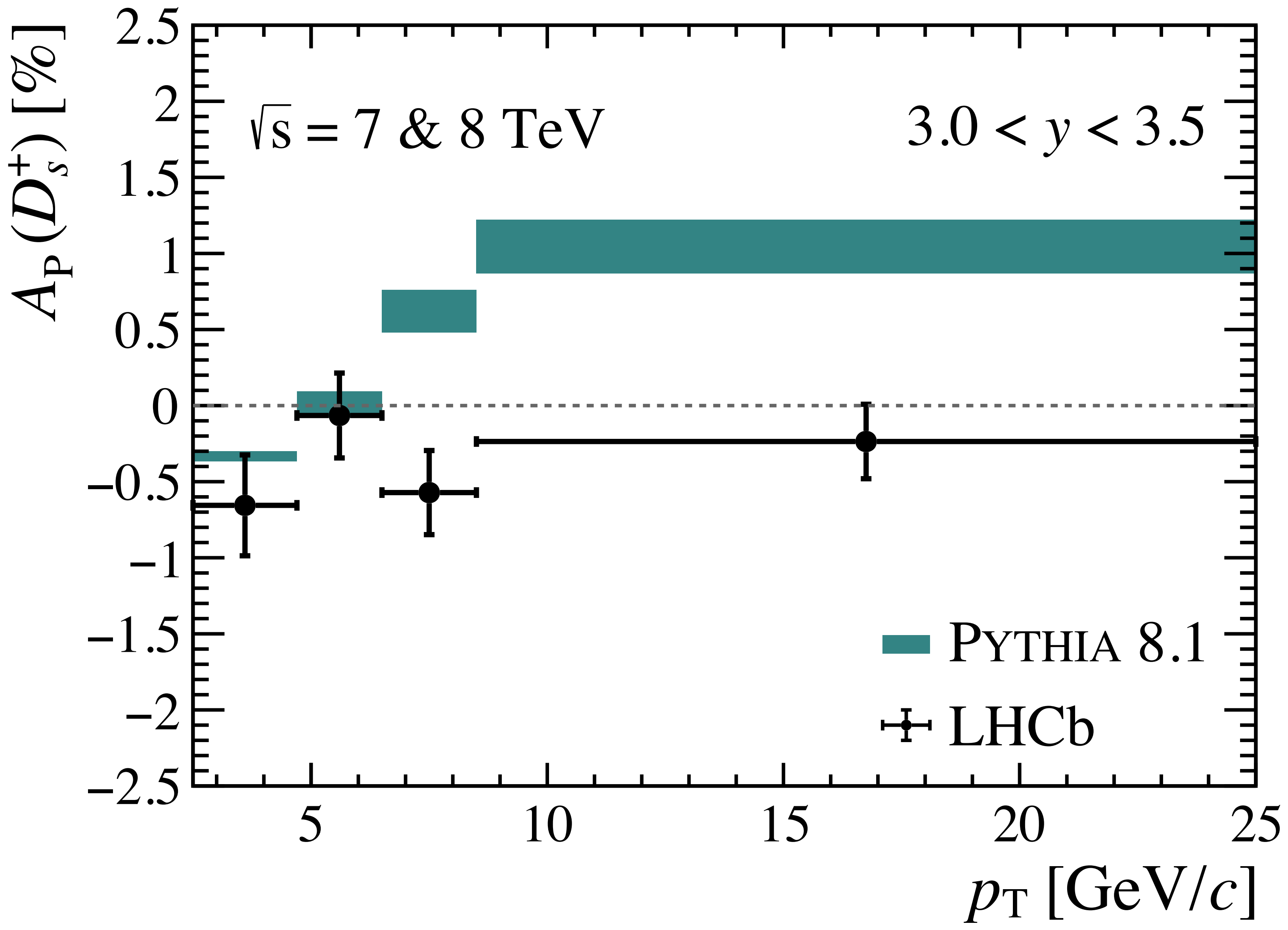
Corresponds to a 3.3σ deviation from the no asymmetry hypothesis

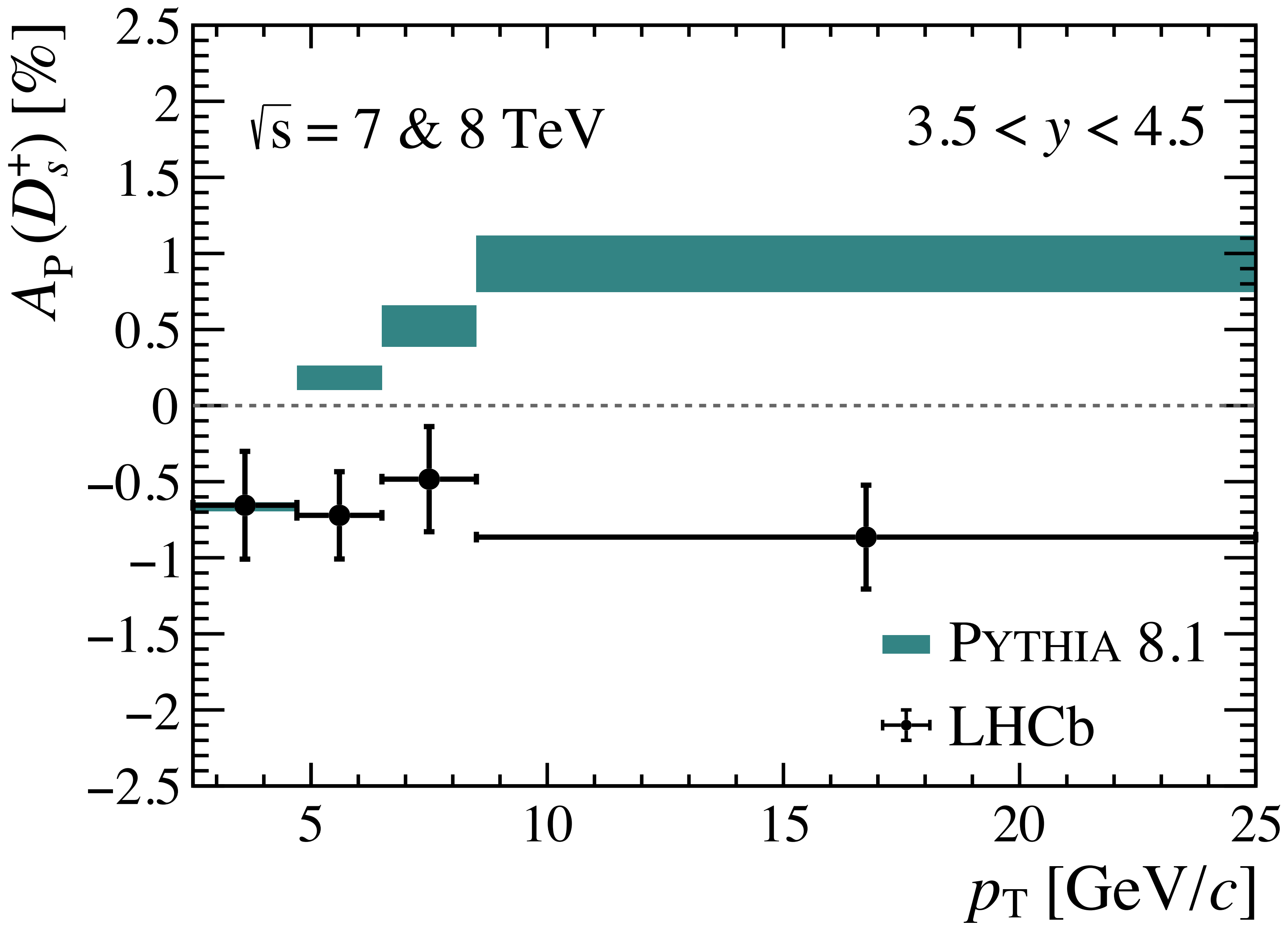
Uncertainties given as: ± statistical ± systematic

Comparison with Pythia

- Pythia includes models for mechanisms that cause production asymmetries
- Compare the LHCb tuning of Pythia 8.1 with these results
  - Pythia predicts a strong dependence in both p_T and y
  - No kinematic dependence found in data





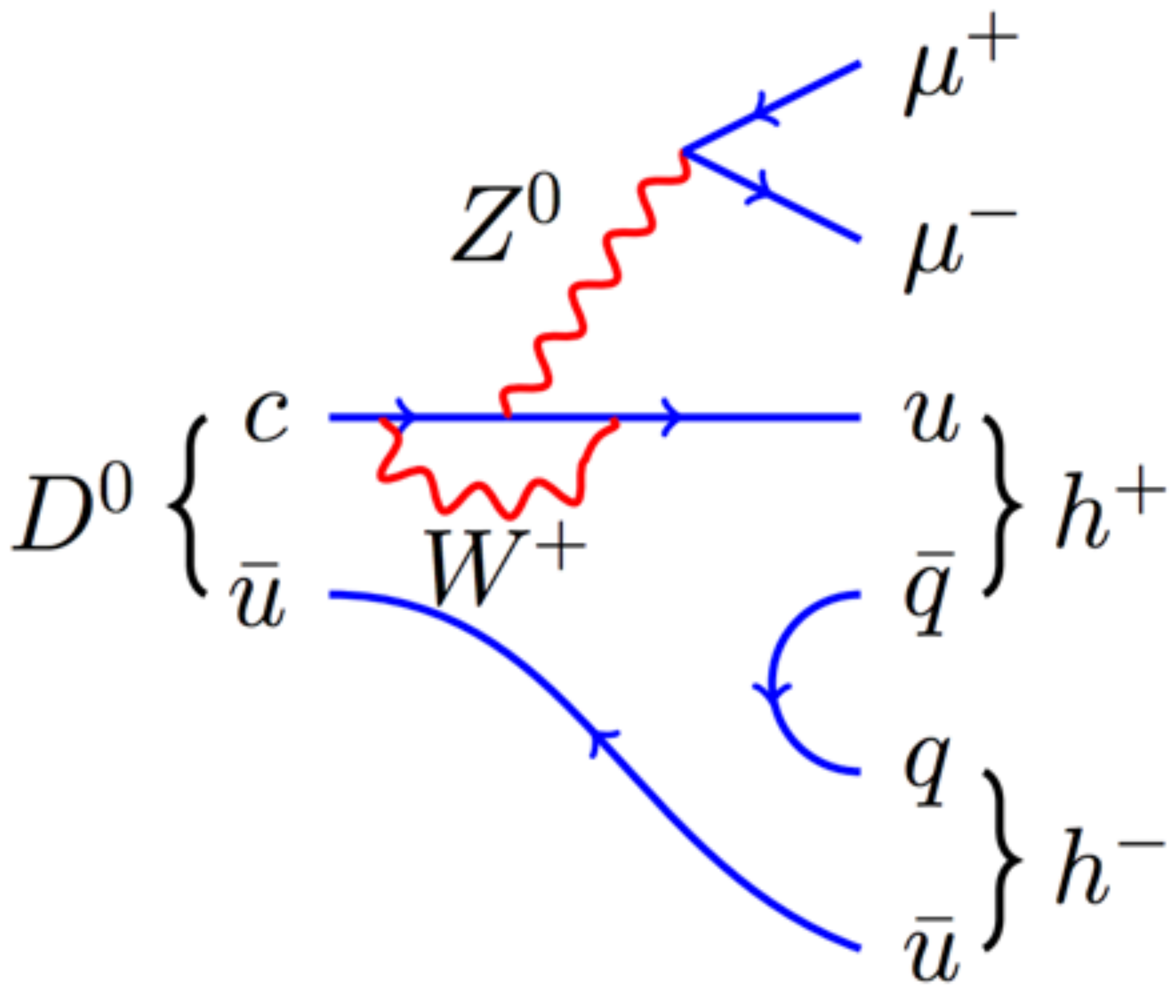


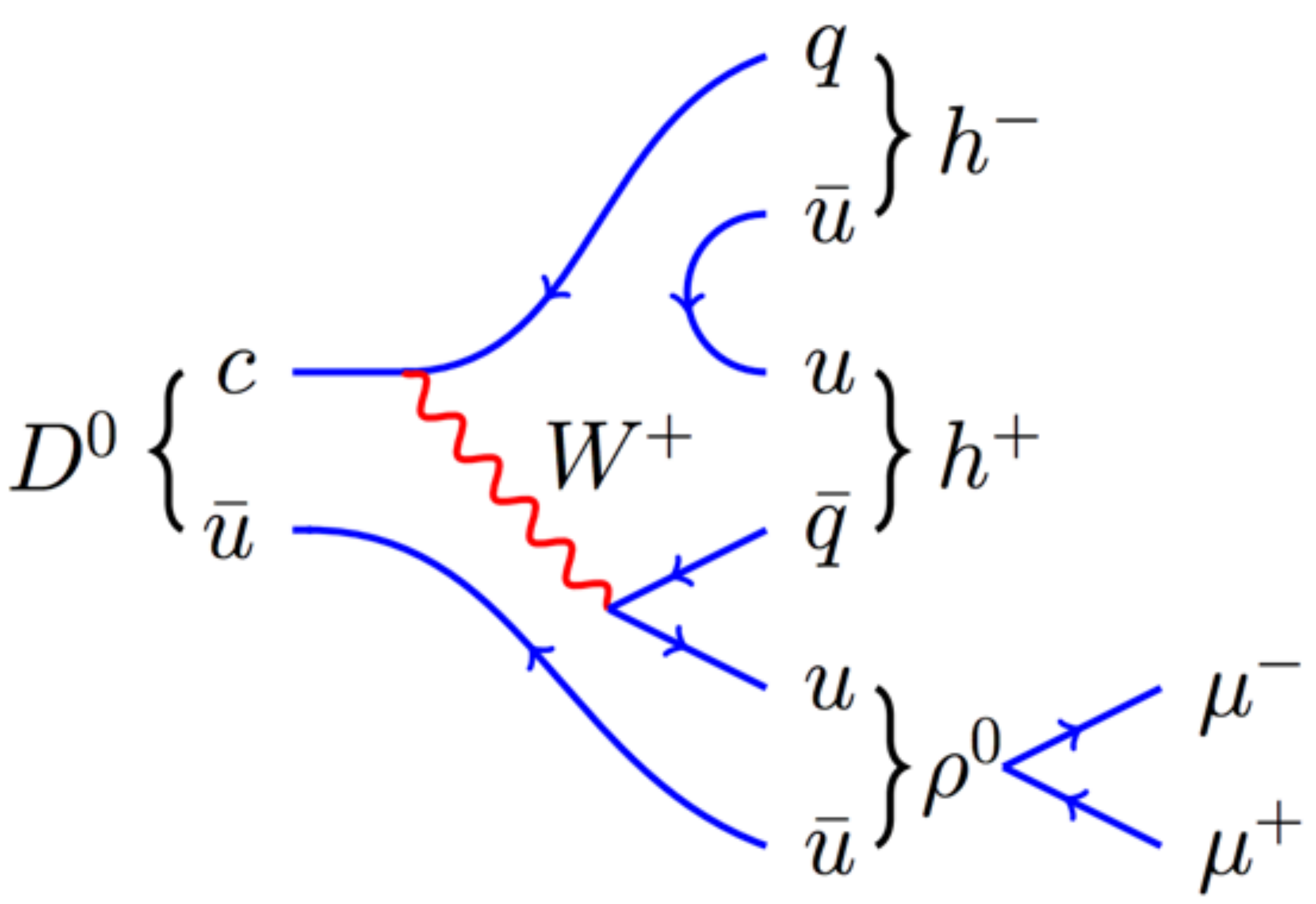
[Phys. Rev. Lett. 121 (2018) 091801]

Measurement of angular and CP asymmetries in $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$ decays

Observation

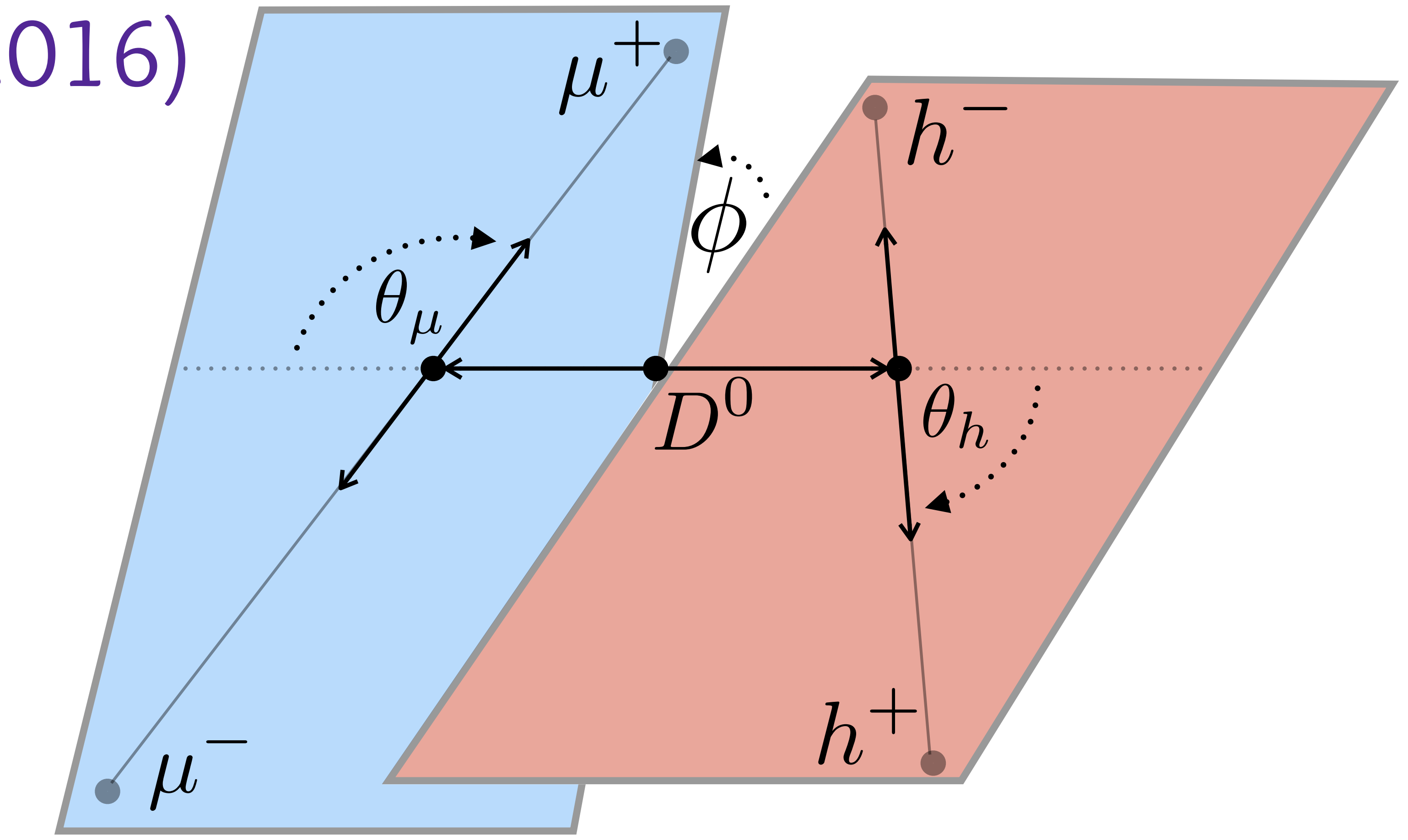
- LHCb recently observed $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$
  - $\mathcal{B}\left(D^0 \to \pi^-\pi^+\mu^+\mu^-\right) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$ [Phys. Rev. Lett. 119, 181805 (2017)]
  - $\mathcal{B}\left(D^0 \to K^-K^+\mu^+\mu^-\right) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$
  - Rarest charm decays observed so far!
- Short distance contributions from FCNC processes (left)
- Long distance contributions at tree level with intermediate resonances (right)





Analysis overview

- Make first measurement of angular and CP asymmetries
  - Also increase data luminosity by 2.5x (previously 2012 data, now 2011-2016)



- Standard model asymmetries are negligibly small
  - Can be inflated up to O(1%) in some BSM models
  - Complimentary to branching ratio measurements

J. High Energy Phys. 04 (2013) 135 Phys. Rev. D 90, 014035 N. Eur. Phys. J. C (2015) 75: 567

- The first measurement of asymmetries that are considered promising probes for new physics: [Phys. Rev. D 93, 074001 (2016)] [Phys. Rev. D 98, 035041 (2018)]

$$A_{FB} = \frac{\Gamma\left(\cos\theta_\mu > 0\right) - \Gamma\left(\cos\theta_\mu < 0\right)}{\Gamma\left(\cos\theta_\mu > 0\right) + \Gamma\left(\cos\theta_\mu < 0\right)}$$

Forward backward asymmetry

$$A_{2\phi} = \frac{\Gamma\left(\sin 2\phi > 0\right) - \Gamma\left(\sin 2\phi < 0\right)}{\Gamma\left(\sin 2\phi > 0\right) + \Gamma\left(\sin 2\phi < 0\right)}$$

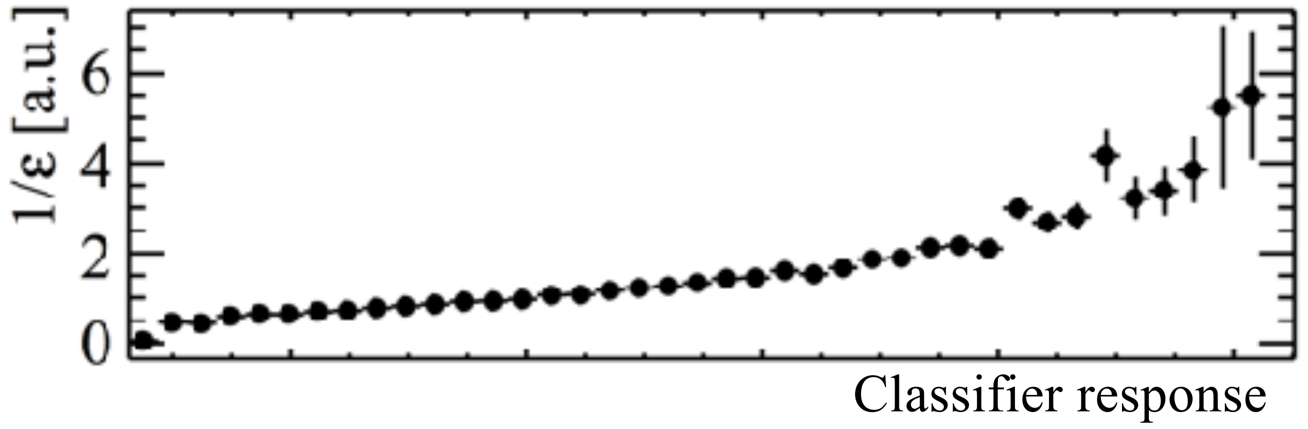
Triple product asymmetry

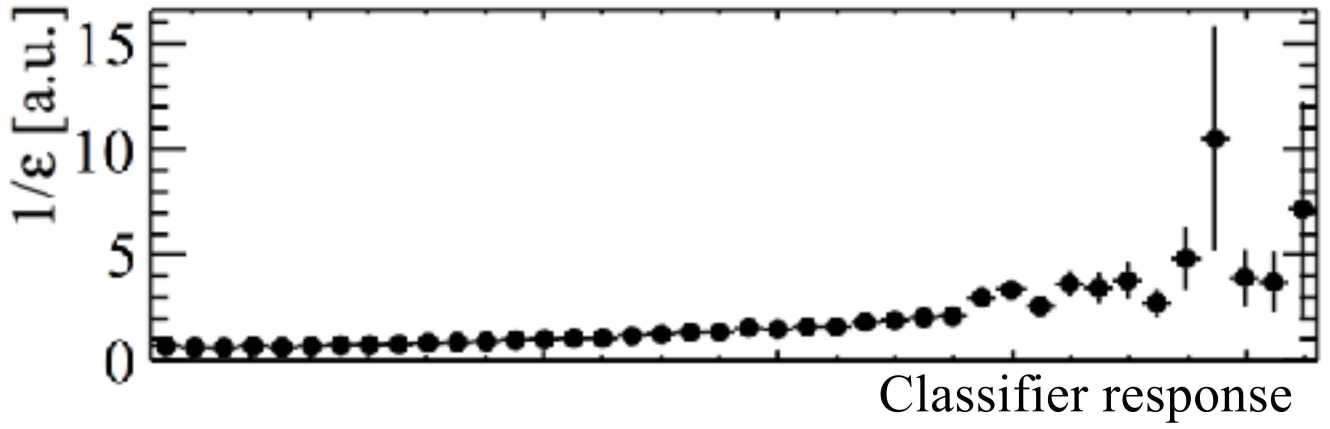
$$A_{CP} = \frac{\Gamma\left(D^0 \to h^+h^-\mu^+\mu^-\right) - \Gamma\left(\bar{D}^0 \to h^+h^-\mu^+\mu^-\right)}{\Gamma\left(D^0 \to h^+h^-\mu^+\mu^-\right) + \Gamma\left(\bar{D}^0 \to h^+h^-\mu^+\mu^-\right)}$$

CP asymmetry

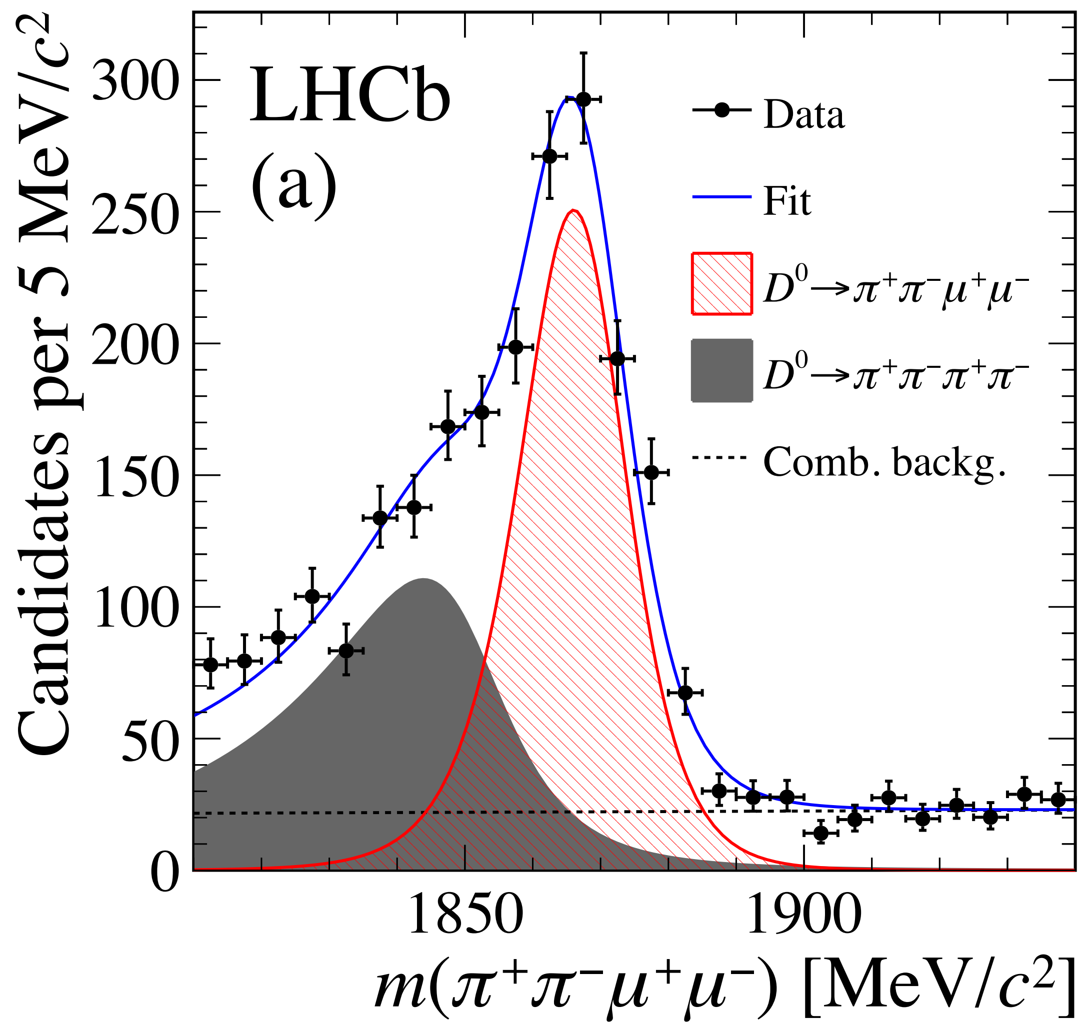
Analysis details

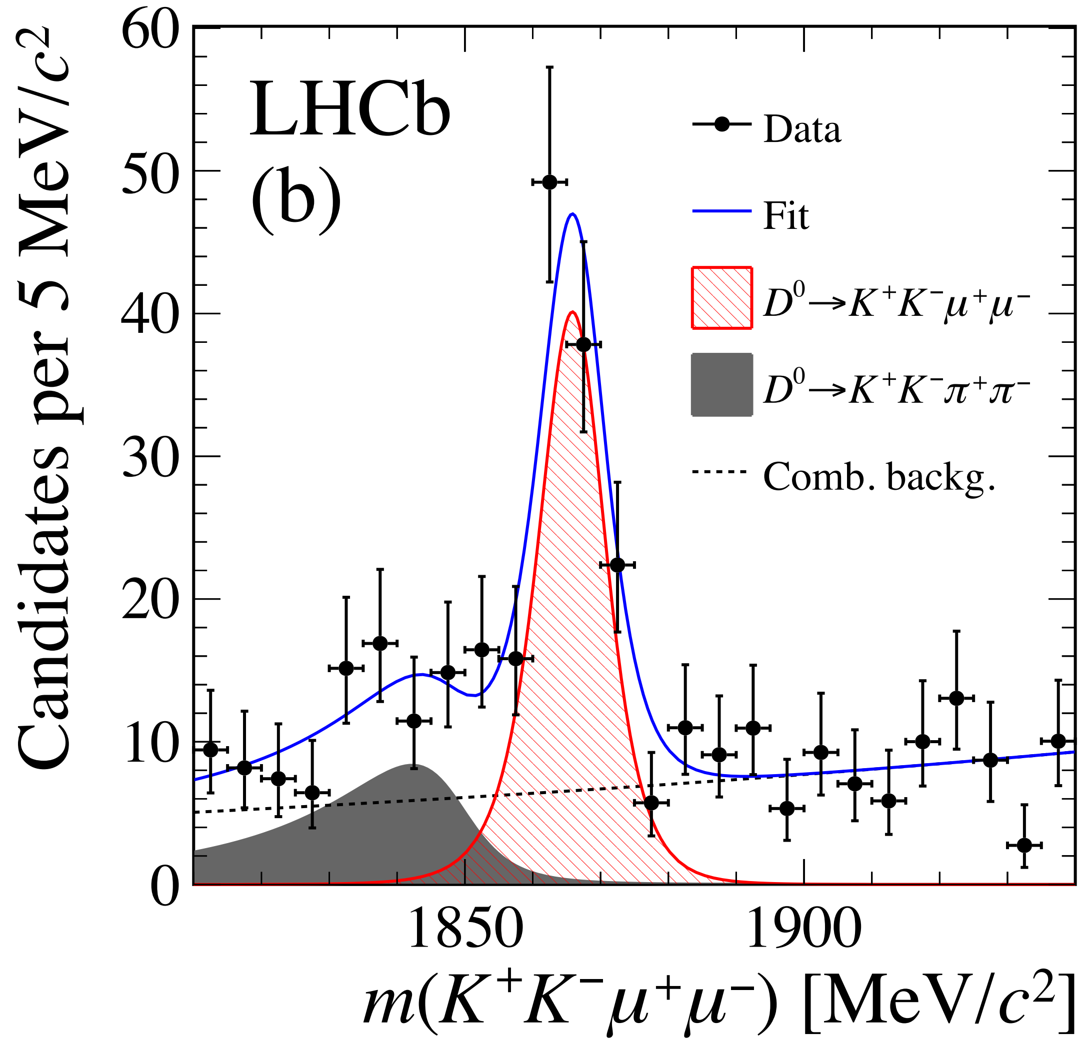
- Using 5 fb^{-1} collected between 2011 and 2016 at $\sqrt{s}$ = 7, 8 and 13 TeV
- Measured integrated and as a function of dimuon mass
  - $\pi\pi$: <525MeV/c^2, η, ρ^0/low-ω, ρ^0/high-ω, ϕ-low, ϕ-high, >1100 MeV/c^2
  - K K: <525MeV/c^2, η, ρ^0/ω
  - Only determined in regions with a significant yield
- Use $D^{*+} \to D^0\pi^+$ decays to tag the flavour of the D^0
- Efficiency variations are corrected by training a BDT
  - Separate simulated decays from before/after applying the selection
  - Correct efficiency using per event weights from the classifier output





Ratio between the generator level and fully selected decays for $\pi\pi$ (left) and KK (right) as a function of classifier output





[Phys. Rev. Lett. 121 (2018) 091801]

Results

$m(\mu^+\mu^-)$ [MeV/c^2]	Signal asymmetries: A_{FB} [%]	$A_{2\phi}$ [%]	A_{CP} [%]
		$D^0 \to \pi^+\pi^-\mu^+\mu^-$	
<525	$2 \pm 20 \pm 2$	$-28 \pm 20 \pm 2$	$17 \pm 20 \pm 2$
525–565	...	...	...
565–780	$8.1 \pm 7.1 \pm 0.7$	$7.4 \pm 7.1 \pm 0.7$	$-12.9 \pm 7.1 \pm 0.7$
780–950	$7 \pm 10 \pm 1$	$-14 \pm 10 \pm 1$	$17 \pm 10 \pm 1$
950–1020	$3.1 \pm 6.5 \pm 0.6$	$1.2 \pm 6.4 \pm 0.5$	$7.5 \pm 6.5 \pm 0.7$
1020–1100	$0.9 \pm 5.6 \pm 0.7$	$1.4 \pm 5.5 \pm 0.6$	$9.9 \pm 5.5 \pm 0.7$
>1100	...	...	...
Full range	$3.3 \pm 3.7 \pm 0.6$	$-0.6 \pm 3.7 \pm 0.6$	$4.9 \pm 3.8 \pm 0.7$
		$D^0 \to K^+K^-\mu^+\mu^-$	
<525	$13 \pm 26 \pm 4$	$9 \pm 26 \pm 3$	$-33 \pm 26 \pm 4$
525–565	...	...	...
>565	$1 \pm 12 \pm 1$	$22 \pm 12 \pm 1$	$13 \pm 12 \pm 1$
Full range	$0 \pm 11 \pm 2$	$9 \pm 11 \pm 1$	$0 \pm 11 \pm 2$

Results integrated across $m(\mu^+\mu^-)$

$$A_{FB}\left(D^0 \to \pi^+\pi^-\mu^+\mu^-\right) = \left(3.3 \pm 3.7 \pm 0.6\right)\%$$

$$A_{2\phi}\left(D^0 \to \pi^+\pi^-\mu^+\mu^-\right) = \left(-0.6 \pm 3.7 \pm 0.6\right)\%$$

$$A_{CP}\left(D^0 \to \pi^+\pi^-\mu^+\mu^-\right) = (4.9 \pm 3.8 \pm 0.7)\%$$

$$A_{FB}\left(D^0 \to K^+K^-\mu^+\mu^-\right) = (0 \pm 11 \pm 2)\%$$

$$A_{2\phi}\left(D^0 \to K^+K^-\mu^+\mu^-\right) = (9 \pm 11 \pm 1)\%$$

$$A_{CP}\left(D^0 \to K^+K^-\mu^+\mu^-\right) = (0 \pm 11 \pm 2)\%$$

- All detection asymmetries are compatible with zero
- No observed dependency on dimuon mass

Uncertainties given as: ± statistical ± systematic

[LHCB-PAPER-2018-033]
(in preparation)

Measurement of the branching fractions of the decays $D^+ \to K^- K^+ K^+$, $D^+ \to \pi^- \pi^+ K^+$ and $D_s^+ \to \pi^- K^+ K^+$

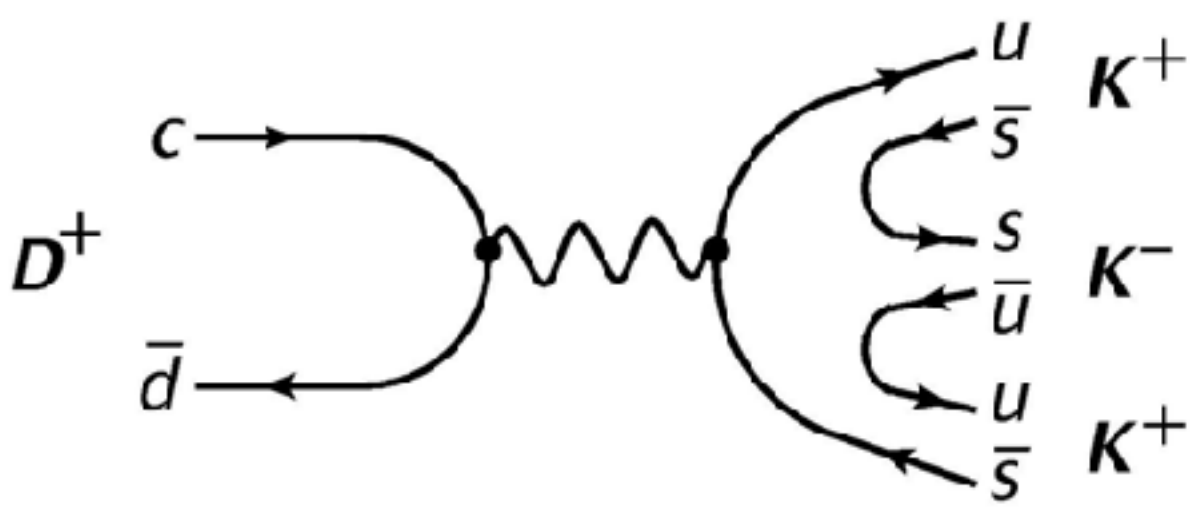
Brand New!

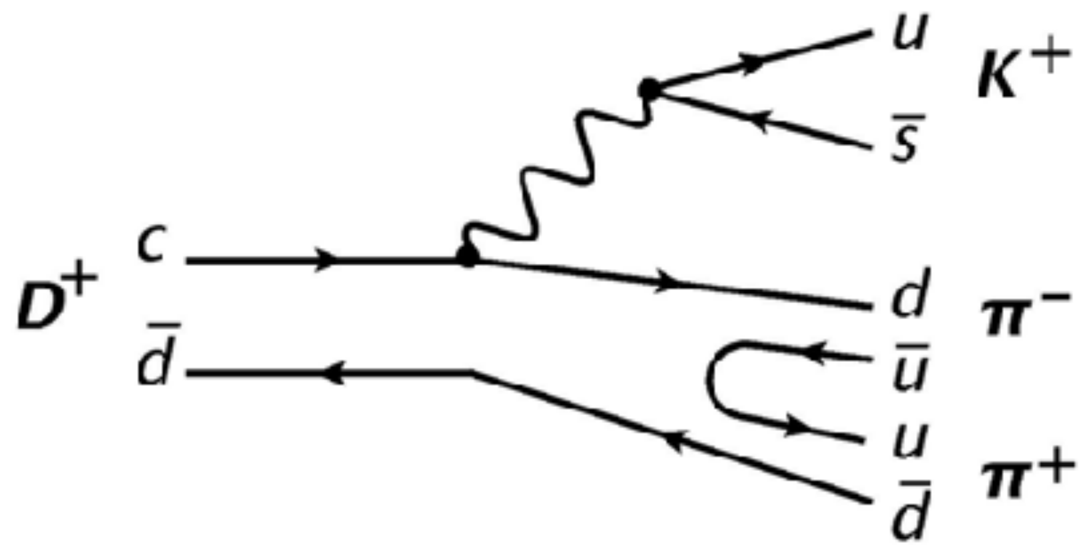
Analysis overview

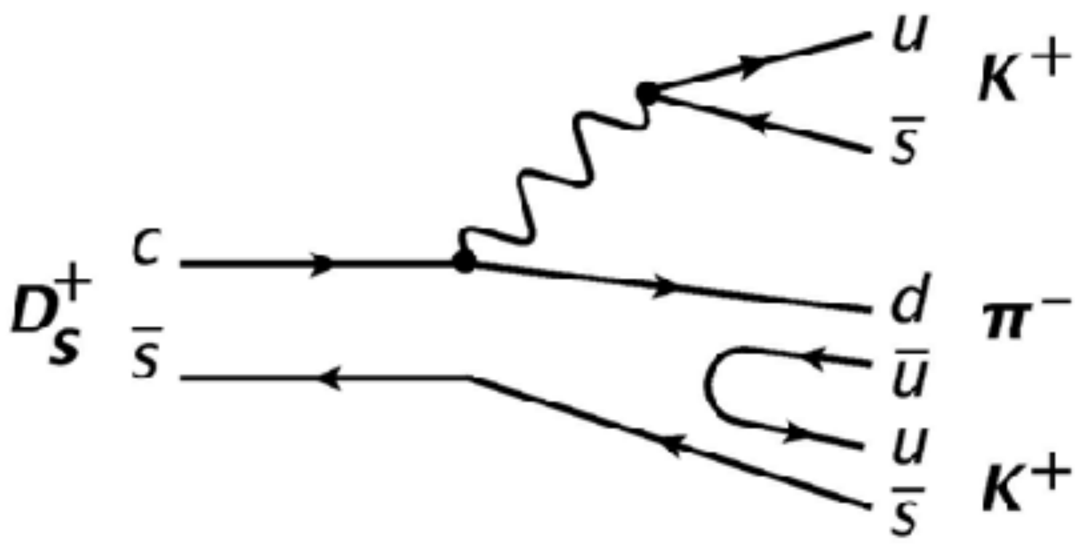
- Large uncertainties in branching fractions for the DCS decays of $D^+_{(s)} \to hhh$
  - Up to 23% uncertainty, previous $D^+ \to K^-K^+K^+$ measurement was based on 65 ± 15 signal candidates
  - LHCb can significantly improve the precision

- Three main measurements of doubly Cabibbo suppressed decays

$$\frac{\mathcal{B}\left(D^+ \to K^-K^+K^+\right)}{\mathcal{B}\left(D^+ \to K^-\pi^+\pi^+\right)} \qquad \frac{\mathcal{B}\left(D^+ \to \pi^-\pi^+K^+\right)}{\mathcal{B}\left(D^+ \to K^-\pi^+\pi^+\right)} \qquad \frac{\mathcal{B}\left(D_s^+ \to \pi^-K^+K^+\right)}{\mathcal{B}\left(D_s^+ \to K^-K^+\pi^+\right)}$$



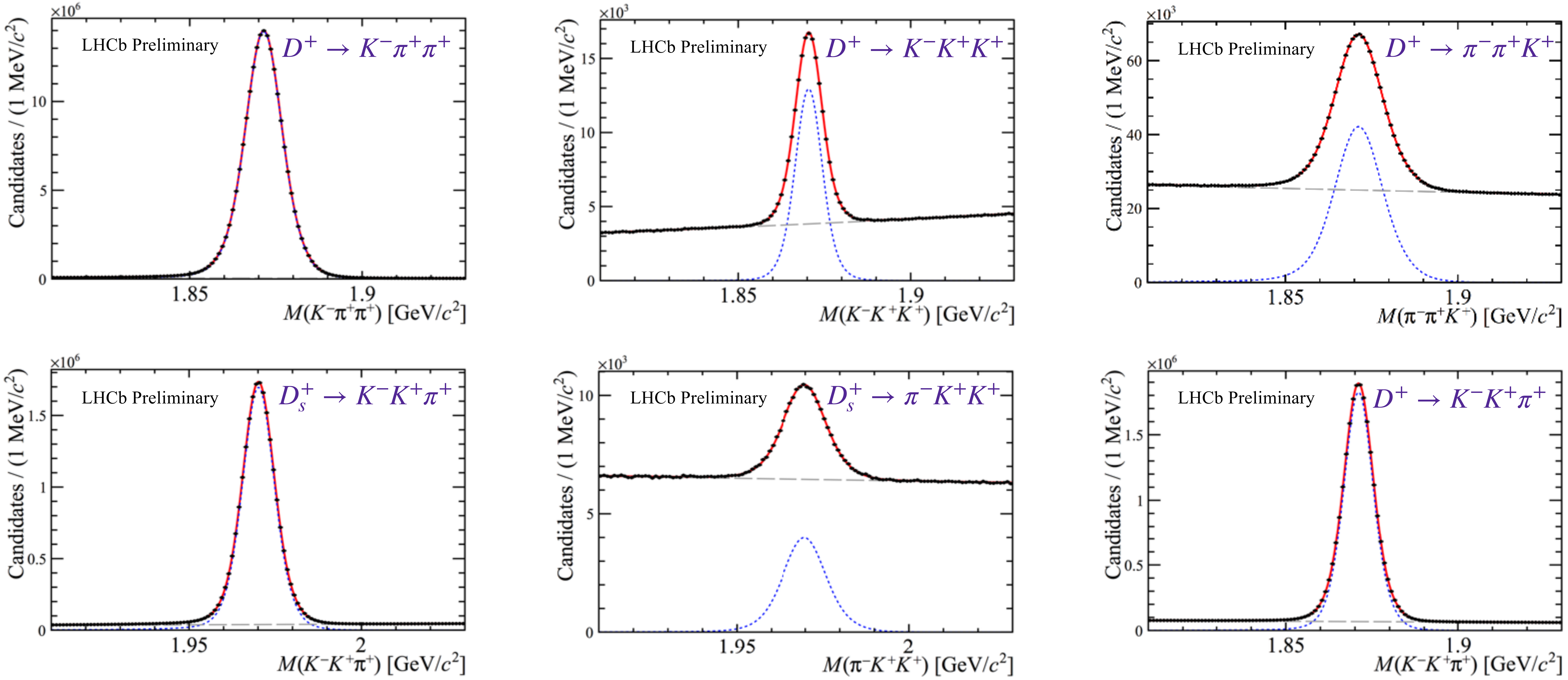




- Also make a control measurement of the CS decay $\dfrac{\mathcal{B}\left(D^+ \to K^-K^+\pi^+\right)}{\mathcal{B}\left(D^+ \to K^-\pi^+\pi^+\right)}$

Fitting

- Determine signal yields from a binned maximum likelihood fit to $M(hhh)$
  - Gaussian and 2 double sided crystal ball distributions used for signal with an exponential for background
  - Data is split by charge, magnet polarity and, for the normalisation channels, $D^+_{(s)}$ momentum



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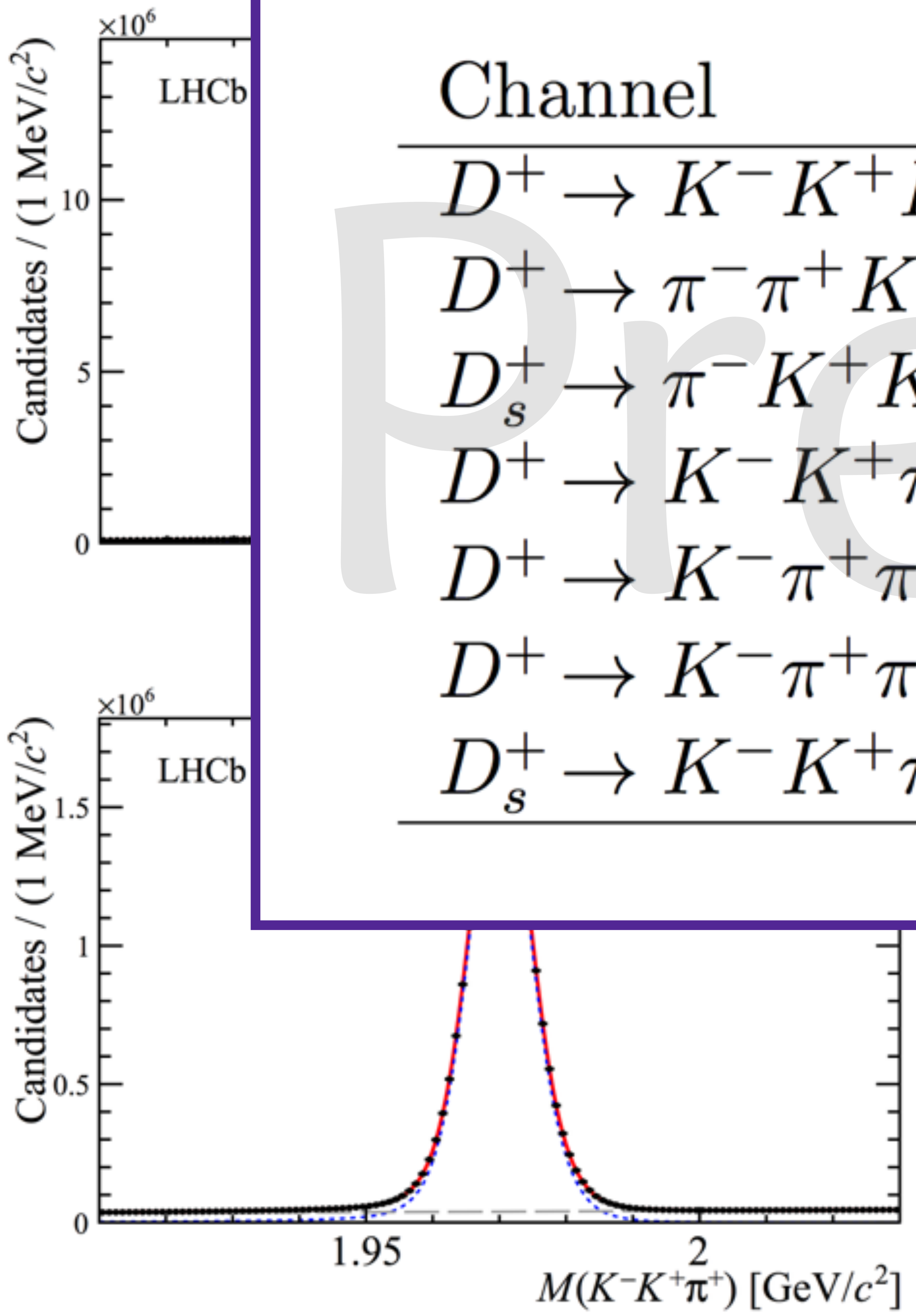
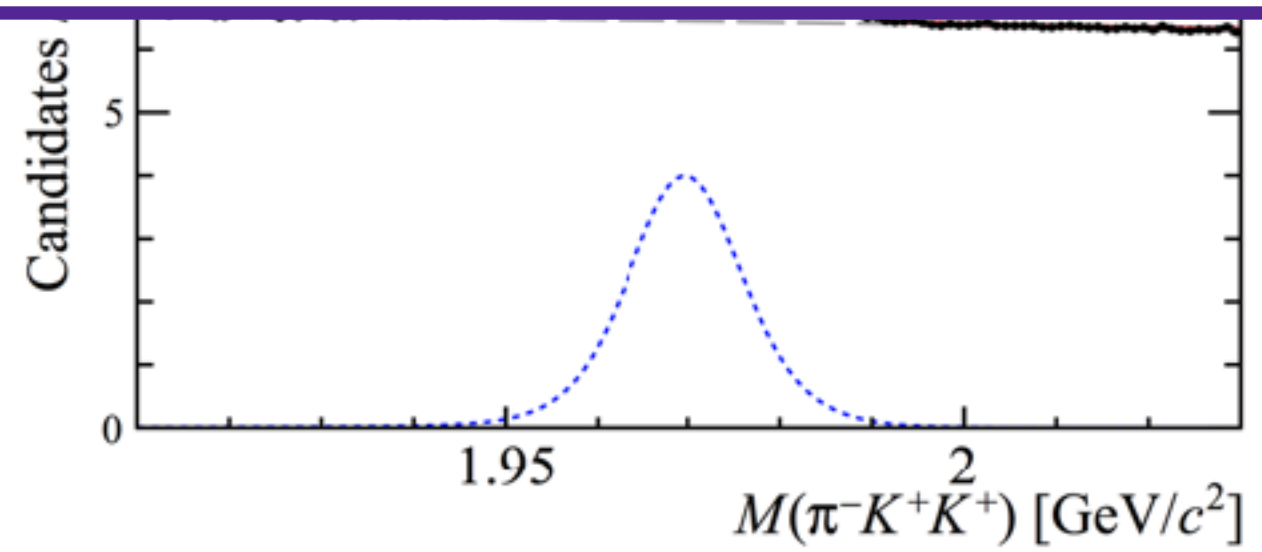
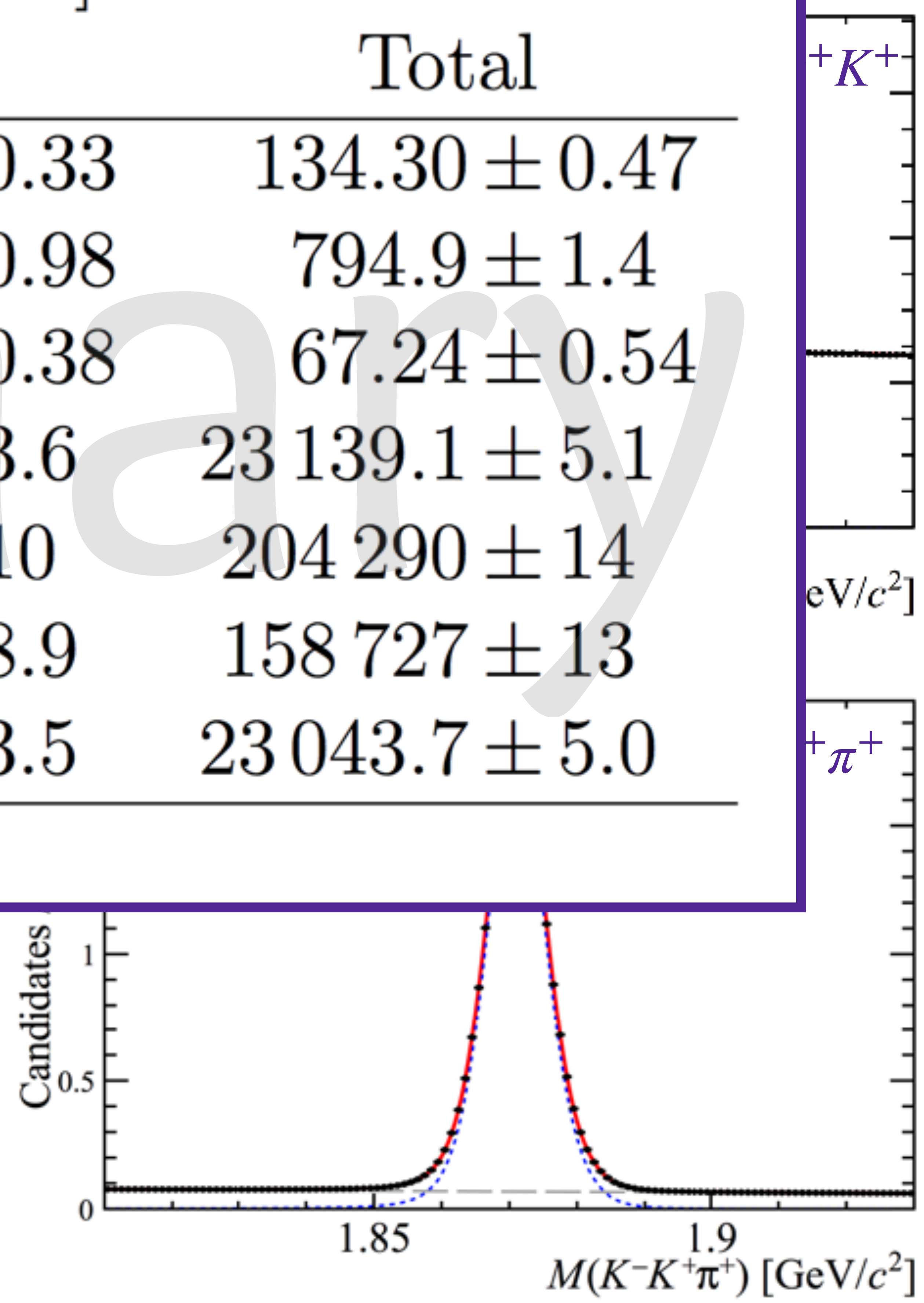




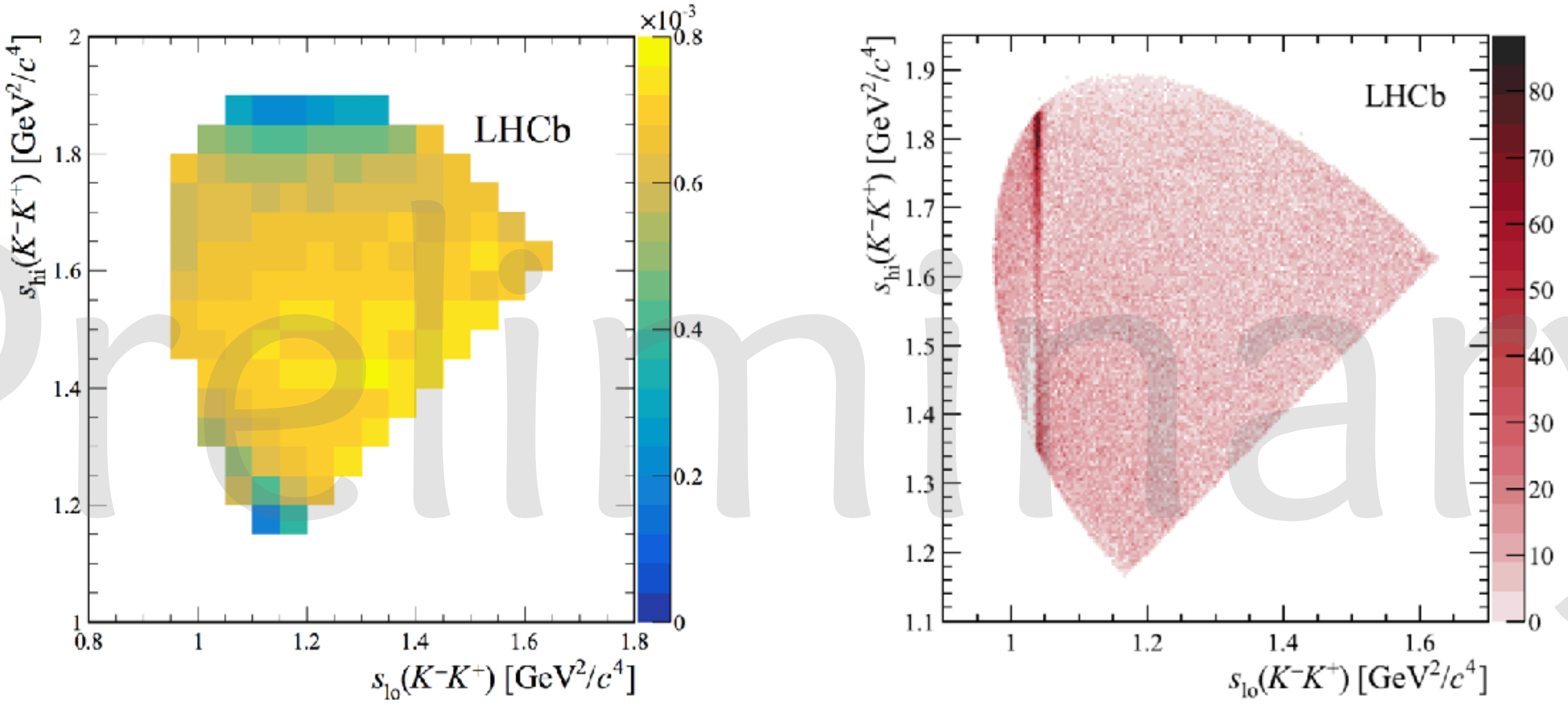


Preliminary

Channel	Yields [$\times 10^3$] *MagDown*	*MagUp*	Total
$D^+ \to K^-K^+K^+$	67.61 ± 0.33	66.69 ± 0.33	134.30 ± 0.47
$D^+ \to \pi^-\pi^+K^+$	401.22 ± 0.99	393.72 ± 0.98	794.9 ± 1.4
$D_s^+ \to \pi^-K^+K^+$	33.68 ± 0.38	33.56 ± 0.38	67.24 ± 0.54
$D^+ \to K^-K^+\pi^+$	$11\,657.1 \pm 3.6$	$11\,482.0 \pm 3.6$	$23\,139.1 \pm 5.1$
$D^+ \to K^-\pi^+\pi^+$ (†)	$103\,282 \pm 10$	$101\,008 \pm 10$	$204\,290 \pm 14$
$D^+ \to K^-\pi^+\pi^+$ (††)	$80\,197.3 \pm 9.0$	$78\,530.2 \pm 8.9$	$158\,727 \pm 13$
$D_s^+ \to K^-K^+\pi^+$	$11\,629.4 \pm 3.5$	$11\,414.3 \pm 3.5$	$23\,043.7 \pm 5.0$

Efficiency corrections

- Selection chosen to suppress both combinatorial and peaking backgrounds
- Efficiencies vary across the Dalitz plane
  - Phase space Monte Carlo is used due to unavailability of a suitable amplitude model
  - Instead the efficiency is computed in O(100) bins in the Dalitz plane



Efficiency map (left) and Dalitz plots (right) for $D^+ \to K^-K^+K^+$

Results

- World's best measurements in all cases

Ratio	PDG 2018	This analysis	Improvement
$\dfrac{\mathcal{B}(D^+ \to K^-K^+K^+)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}$	$(9.5 \pm 2.2) \times 10^{-4}$	$(6.541 \pm 0.025 \pm 0.042) \times 10^{-4}$	45
$\dfrac{\mathcal{B}(D^+ \to \pi^-\pi^+K^+)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}$	$(5.77 \pm 0.22) \times 10^{-3}$	$(5.231 \pm 0.009 \pm 0.023) \times 10^{-3}$	9
$\dfrac{\mathcal{B}(D_s^+ \to \pi^-K^+K^+)}{\mathcal{B}(D_s^+ \to K^-K^+\pi^+)}$	$(2.33 \pm 0.23) \times 10^{-3}$	$(2.372 \pm 0.024 \pm 0.025) \times 10^{-3}$	6.5
$\dfrac{\mathcal{B}(D^+ \to K^-K^+\pi^+)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}$	$(10.59 \pm 0.18)\,\%$	$(10.282 \pm 0.002 \pm 0.068)\,\%$	2.5

Uncertainties given as: ± statistical ± systematic

- World's best measurements in all cases
- Combining with the PDG 2018 average for the denominator:

$$\mathcal{B}\left(D^+ \to K^-K^+K^+\right) = \left(5.87 \pm 0.02 \pm 0.04 \pm 0.18\right) \times 10^{-5}$$

$$\mathcal{B}\left(D^+ \to \pi^-\pi^+K^+\right) = \left(4.70 \pm 0.01 \pm 0.02 \pm 0.15\right) \times 10^{-4}$$

$$\mathcal{B}\left(D_s^+ \to \pi^-K^+K^+\right) = \left(1.293 \pm 0.013 \pm 0.014 \pm 0.040\right) \times 10^{-4}$$

$$\mathcal{B}\left(D^+ \to K^-K^+\pi^+\right) = \left(9.233 \pm 0.002 \pm 0.061 \pm 0.288\right) \times 10^{-3}$$

Uncertainties given as: ± statistical ± systematic ± normalisation channel branching ratio

Conclusions

- LHCb is a charm factory and has the world's largest sample of charm decays
- Huge samples allow for rare and high precision measurements to be made
- Many more analyses to come using Run 1 and Run 2 data
- Longer term: LHCb's first upgrade begins at the end of the year
  - Will allow for measurements with an order of magnitude larger samples

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Any Questions?