LHCb as a Charm Factory

Adam Davis

On Behalf of the LHCb Collaboration

5 June, 2018

IS

LHCb ~~as~~ a Charm Factory

Adam Davis
On Behalf of the LHCb Collaboration

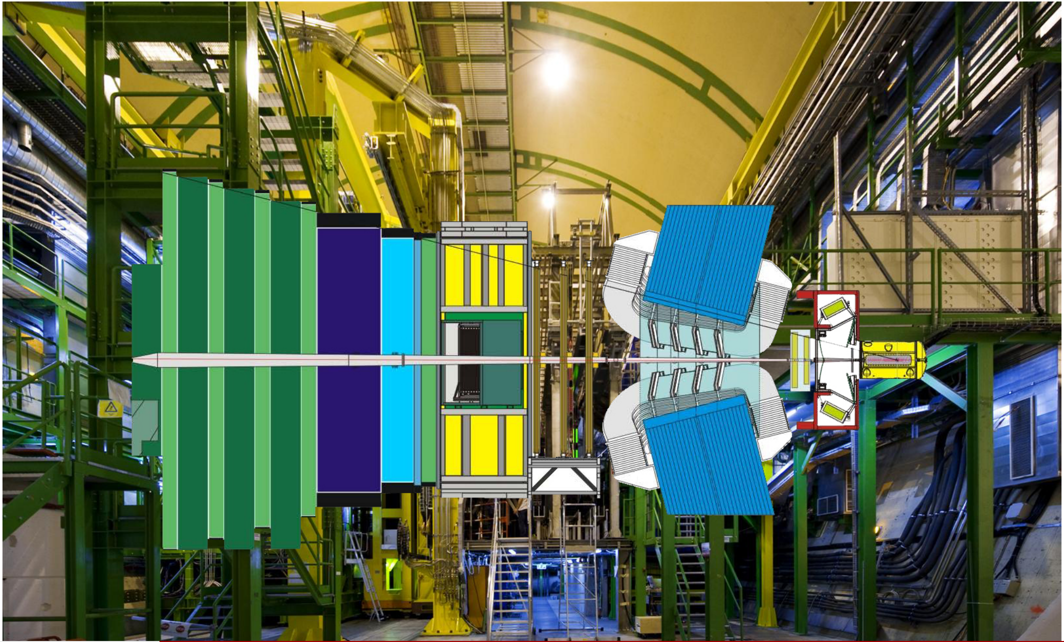
5 June, 2018

LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009

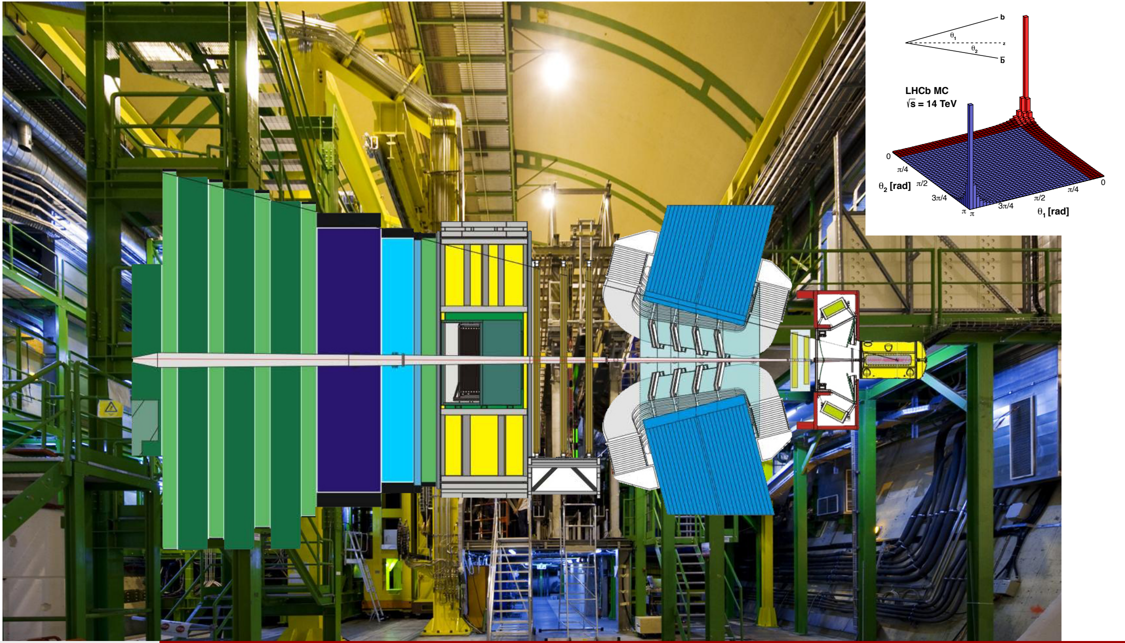
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



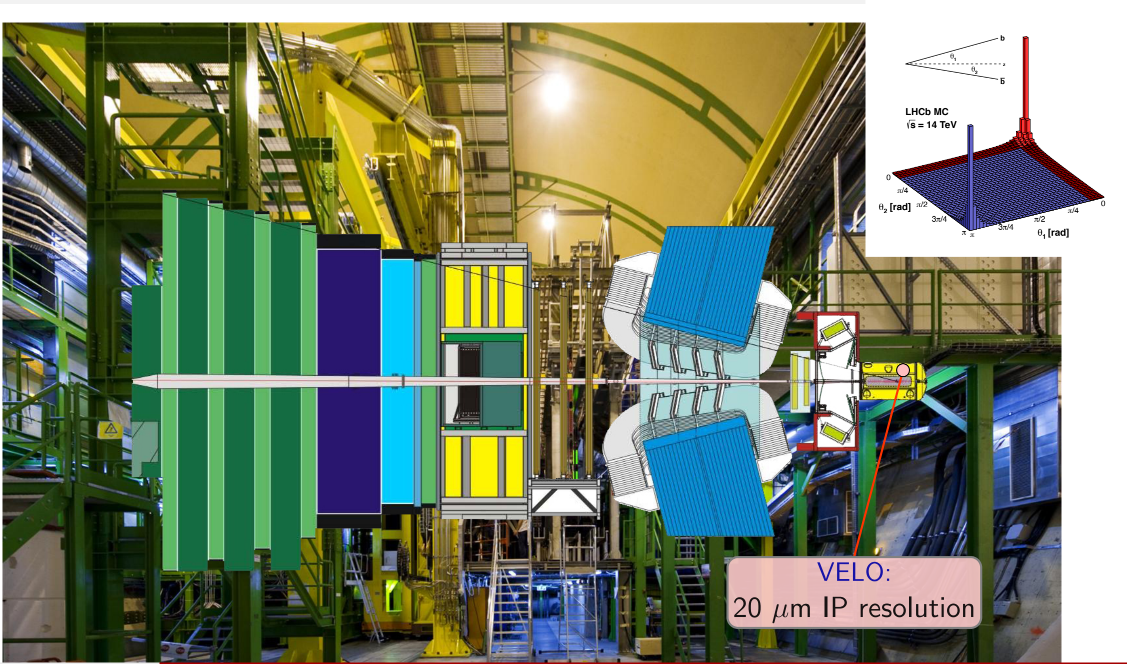
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



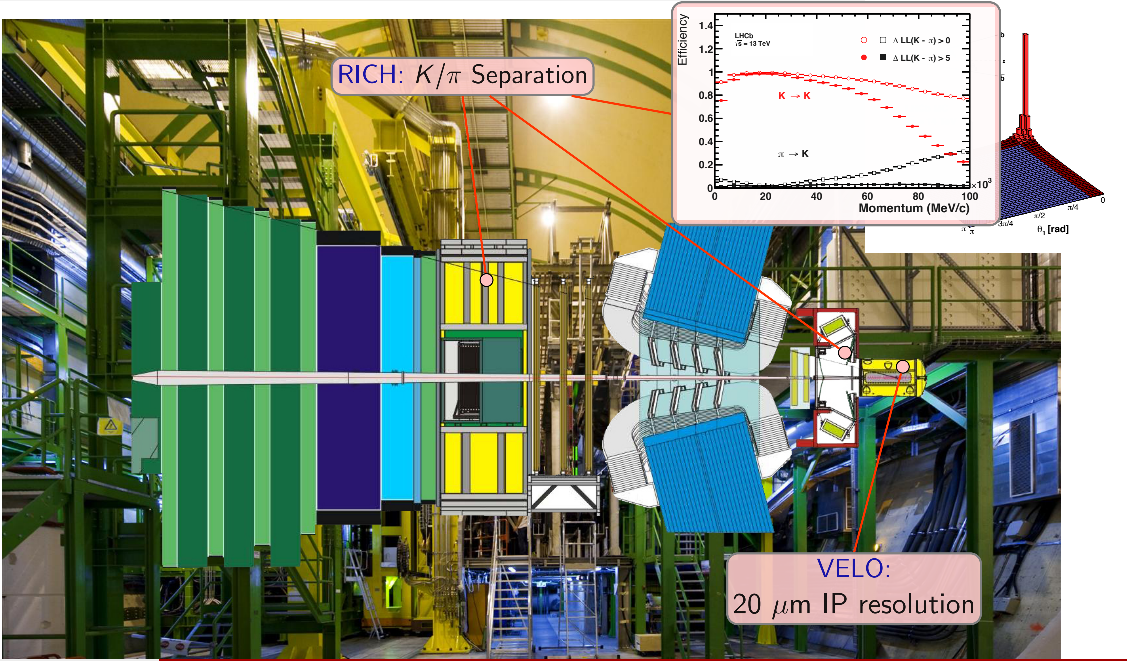
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



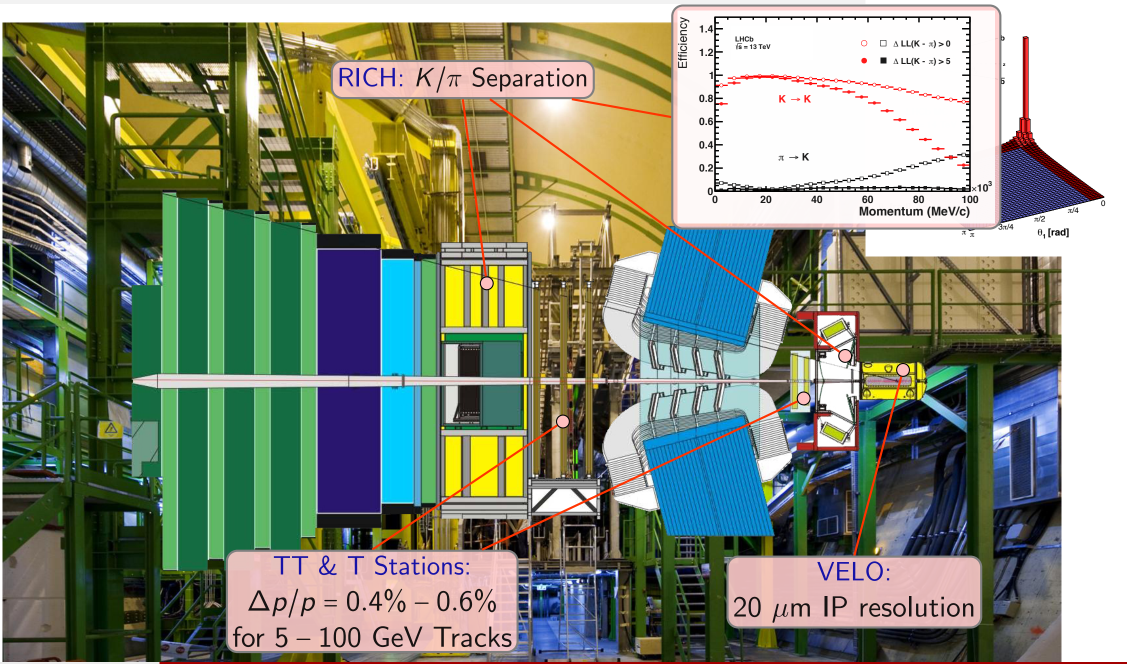
LHCb

[Int. J. Mod. Phys. A 30, 1530022 (2015)](), [10.1016/NIMA.2017.03.009]()



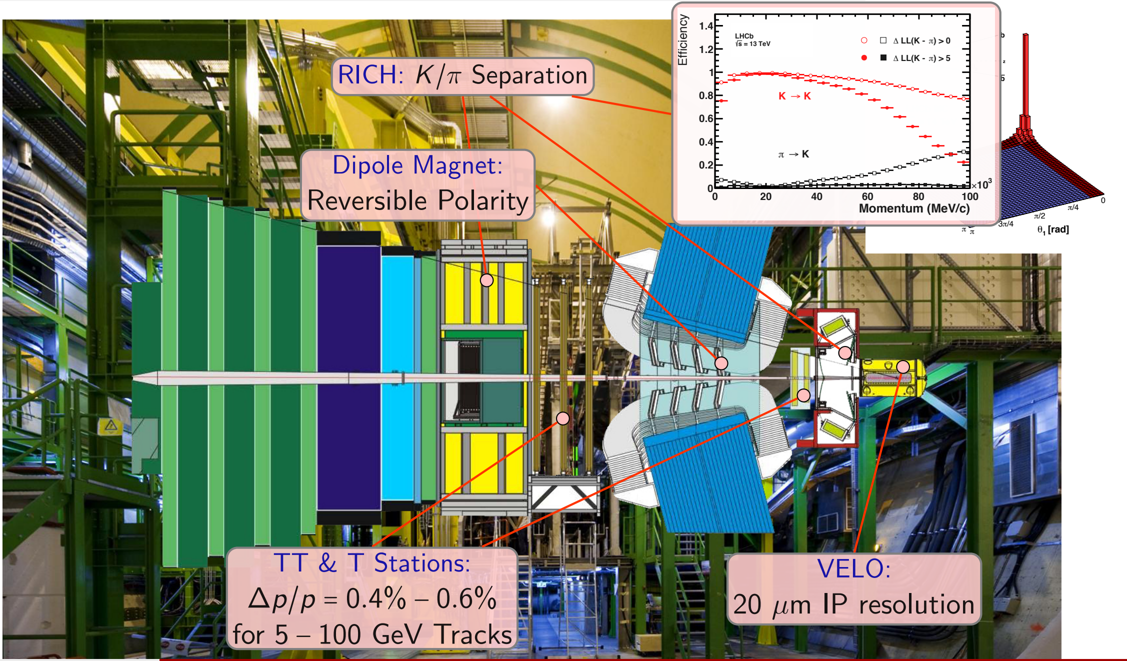
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



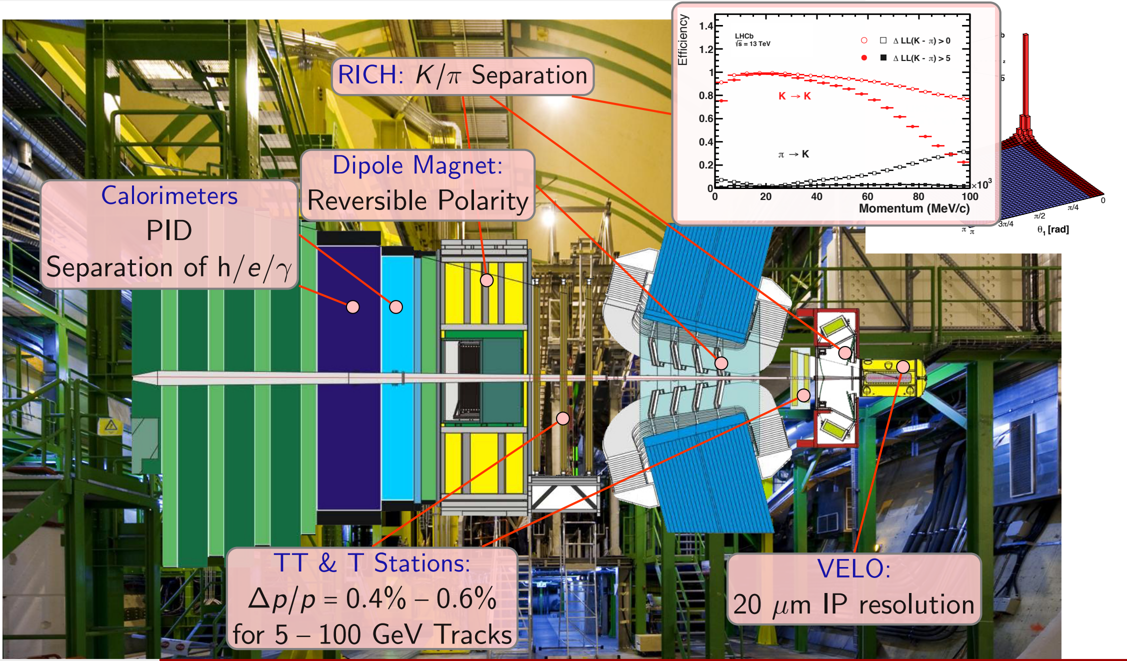
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



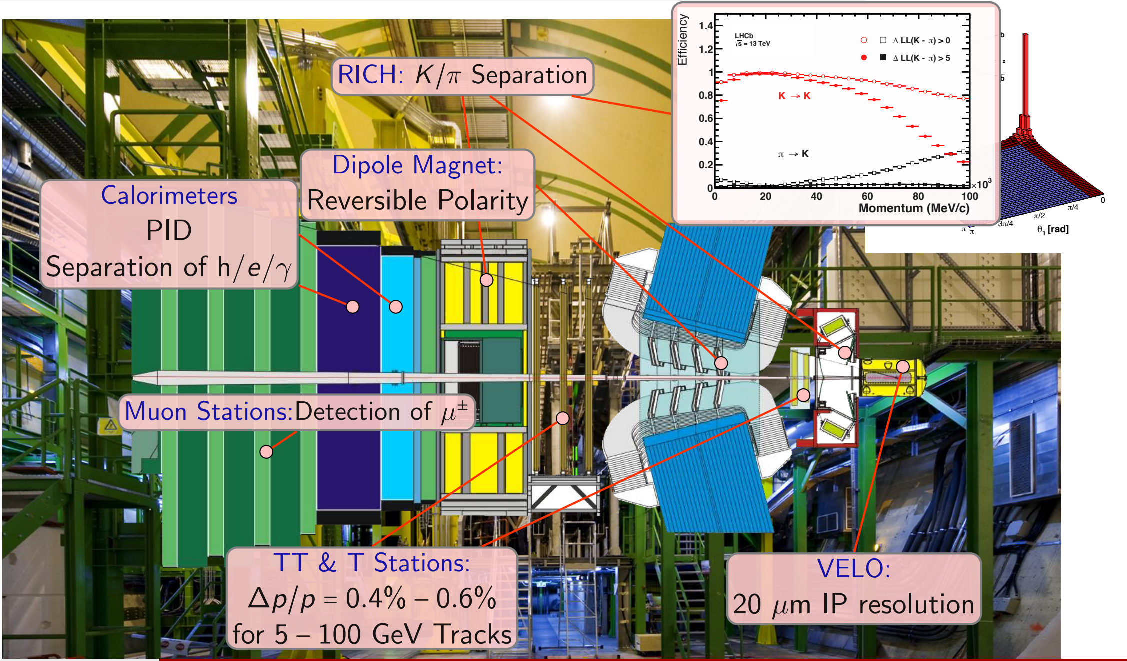
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



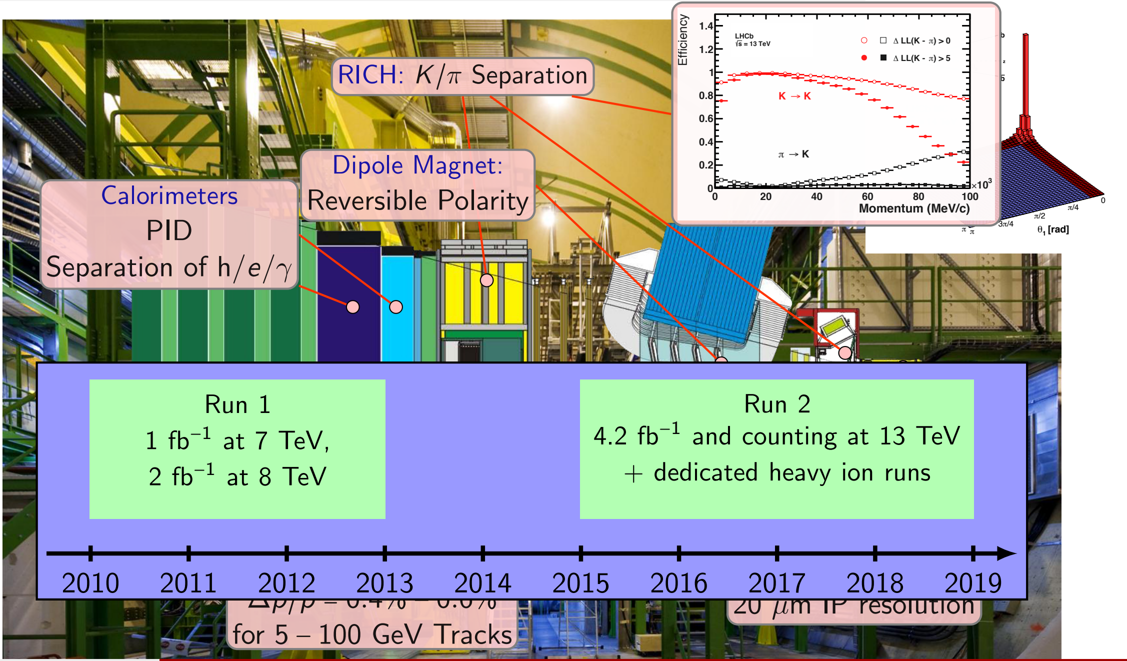
LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



LHCb

Int. J. Mod. Phys. A 30, 1530022 (2015), 10.1016/NIMA.2017.03.009



Run 1
1 fb^{-1} at 7 TeV,
2 fb^{-1} at 8 TeV

Run 2
4.2 fb^{-1} and counting at 13 TeV
+ dedicated heavy ion runs

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

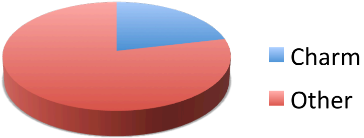
Why is LHCb a Charm Factory?

- In 2017, $>5\%$ of all bunch crossings produced a charm meson within LHCb acceptance
  (13 TeV, $2<\eta<4.5, 0<p_T<8\mathrm{GeV}/c$)
  JHEP 05 (2017) 074

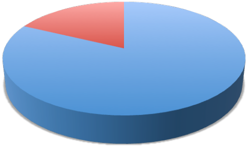
$$\sigma(pp\to D^0X) = 2072\pm 2\pm 124\mu\mathrm{b}$$
$$\sigma(pp\to D^+X) = 834\pm 2\pm 78\mu\mathrm{b}$$
$$\sigma(pp\to D_s^+X) = 353\pm 9\pm 76\mu\mathrm{b}$$
$$\sigma(pp\to D^{*+}X) = 784\pm 4\pm 87\mu\mathrm{b}$$

- 1.4 billion charm hadron decays reconstructed between 2011 and 2015
- High rates $\to$ new strategies necessary
- Custom “turbo” triggers which save only required information

‘Traditional’ triggers:
~10 kHz total
~600 MB/s

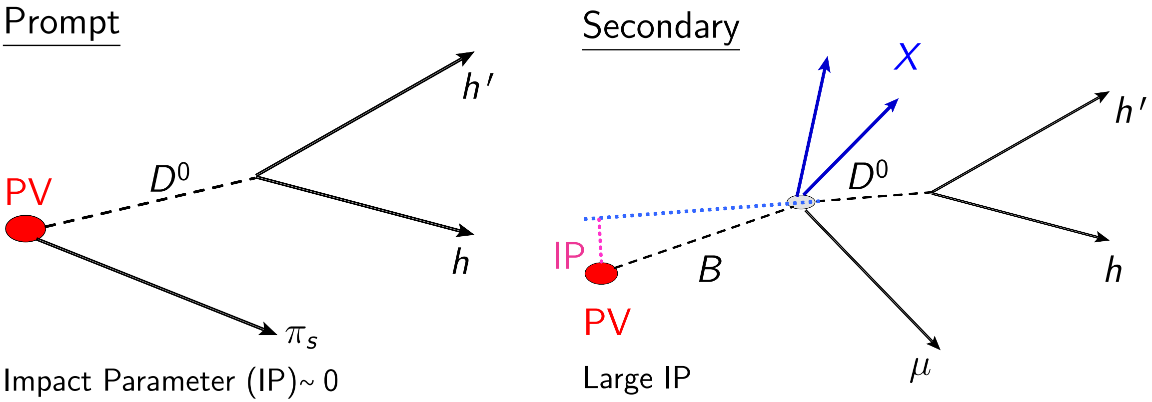


Turbo triggers:
~3 kHz total
~60 MB/s



Experimental Strategies

- Reconstruct charm decays with two topologies



- Use IP and related quantities to distinguish prompt and secondaries

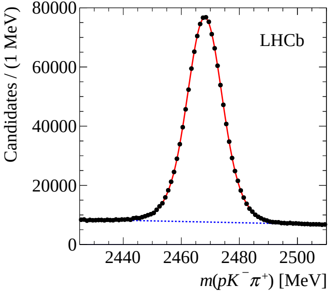
Production & Decay Properties

Ω_c spectroscopy

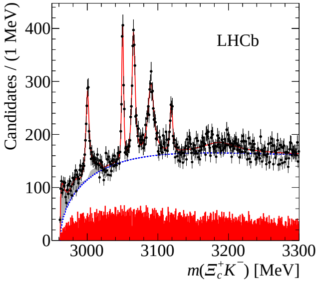
[Phys. Rev. Lett. 118 (2017) 182001]

- Spectroscopy of cqq' states is intricate
- Search for new Ω_c^0 resonances by looking at $\Xi_c^+(\to pK^-\pi^+)K^-$ mass spectrum using Run I +2015 data
- Observation of five previously unknown states
- Fit improves when adding additional broad structure/multiple resonances at 3188 MeV/c^2

$\sim$ 1M $\Xi_c \to pK^-\pi^+$



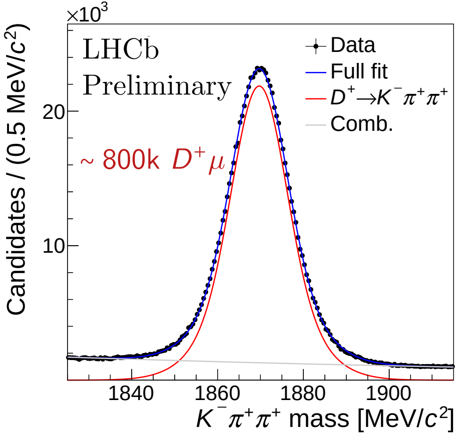
Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	$970 \pm 60 \pm 20$	20.4
		< 1.2 MeV, 95% CL		
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	$480 \pm 70 \pm 30$	10.4
		< 2.6 MeV, 95% CL		
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{\rm fd}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{\rm fd}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{\rm fd}$			$190 \pm 70 \pm 20$	

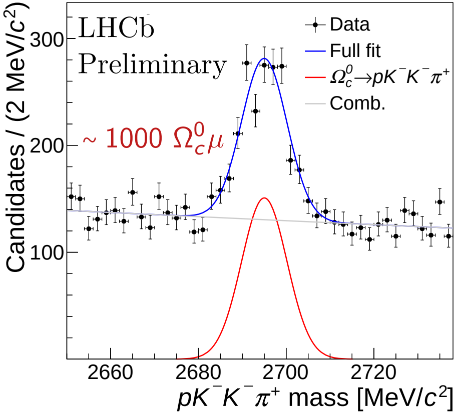


NEW: Ω_c^0 lifetime

[LHCb-PAPER-2018-028 in prep.]

- Conventional hierarchy of charmed lifetimes argued to be $\tau_{\Xi_c^+} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0} > \tau_{\Omega_c^0}$
- Least well measured is Ω_c^0, 69 ± 12 fs from FOCUS, WA89 and E687
- Use $\Omega_c^0 \to pK^-K^-\pi^+$ from $\Omega_b^- \to \Omega_c^0\mu^-\overline{\nu}_\mu X$ using Run I data
- Use $\overline{B}^0 \to D^+\mu^-\bar{\nu}_\mu X$ as a calibration channel





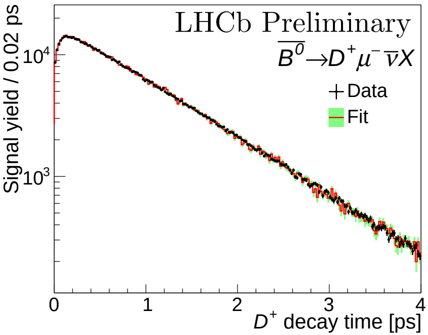
NEW: Ω_c^0 lifetime

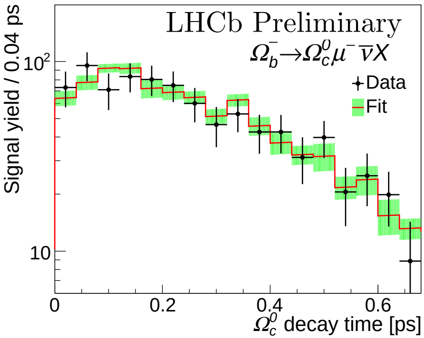
[LHCb-PAPER-2018-028 in prep.]

- Measure $r_{\Omega_c^0} = \frac{\tau_{\Omega_c^0}}{\tau_{D^+}}$ after subtraction of background from fit to invariant mass
- Simultaneous fit of B^0 and Ω_b^- samples

$$r_{\Omega_c^0} = 0.258 \pm 0.023 \pm 0.010$$

$$\tau_{\Omega_c} = 268 \pm 24(stat) \pm 10(syst) \pm 2(\tau_{D^+})\text{fs}$$



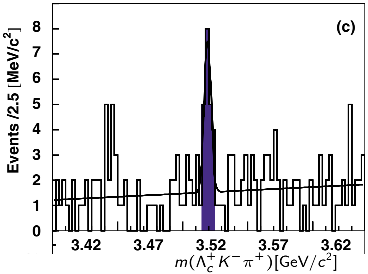


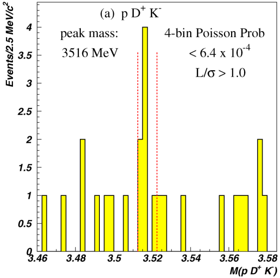
Source	$r_{\Omega_c^0}$
Decay time acceptance	13
Ω_b^- prod. spectrum	3
Ω_b^- lifetime	4
Decay time resolution	3
Background subtraction	18
$H_c(\tau^-, D)$, random μ^-	8
Simulated sample size	98
Total systematic	101
Statistical uncertainty	230

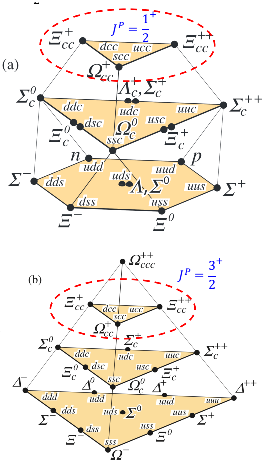
- Inconsistent with current measurement by factor of ~4(!)
- Hierarchy appears instead to read $\tau_{\Xi_c^+} > \tau_{\Omega_c^0} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0}$

- $C = 2$ SU(4) multiplet has isospin doublet $(\Xi_{cc}^{+}, \Xi_{cc}^{++})$ and singlet (Ω_{cc}^{++})
- if $J^P = \frac{1}{2}$, decays weakly, otherwise decays strongly
- Due to isospin symmetry, $m(\Xi_{cc}^{+}) \simeq m(\Xi_{cc}^{++})$
- SELEX claimed observation of Ξ_{cc}^{+}

PRL.89.112001 PLB 628:18-24,2005







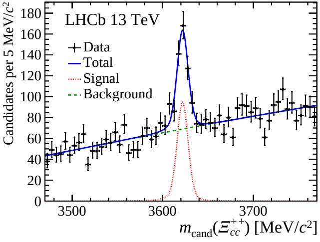
- Observed in $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ and $\Xi_{cc}^{+} \to p D^+ K^-$ with lifetime $\tau_{\Xi_{cc}^{+}} < 33$ fs @90% CL
- Not confirmed by FOCUS, Belle, BaBar, LHCb

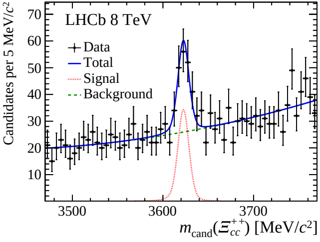
Ξ_{cc}^{++}, a recap (2)

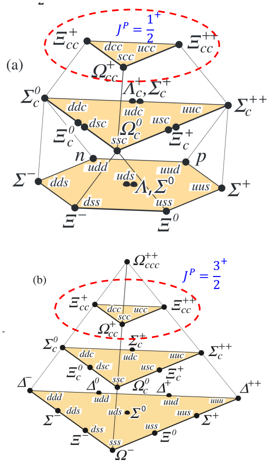
[PRL 119, 112001 (2017)]

- $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ identified as most promising discovery channel [1703.09086]
- Observed by LHCb in both 8 and 13 TeV datasets

313 ± 33 Ξ_{cc}^{++} 113 ± 21



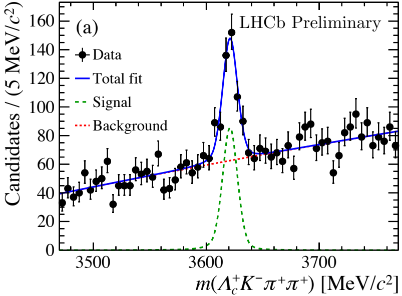


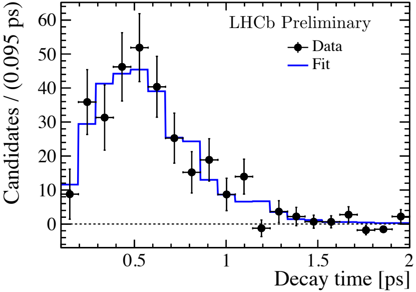


$$3621.40 \pm 0.72(stat) \pm 0.27(syst.) \pm 0.14(\Lambda_c^+)\text{MeV}/c^2$$

- Invariant mass inconsistent with SELEX by greater than 100 MeV$/c^2$ $\to$inconsistent with being isospin partner
- Missing piece of the puzzle: lifetime

- Measure $\tau(\Xi_{cc}^{++})$ with efficiencies given relative to control channel $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$





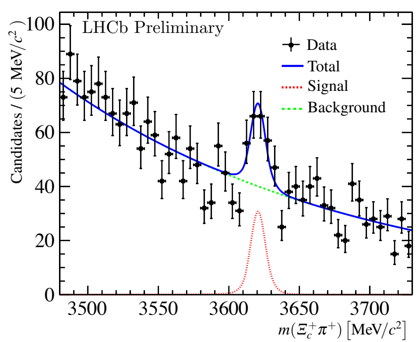
$$\tau(\Xi_{cc}^{++}) = 0.256^{+0.024}_{-0.022}(stat) \pm 0.014(syst)\,ps$$

Source	Uncertainty (ps)
Signal and background mass models	0.005
Correlation of mass and decay-time	0.004
Binning	0.001
Data-simulation differences	0.004
Resonant structure of decays	0.011
Hardware trigger threshold	0.002
Simulated Ξ_{cc}^{++} lifetime	0.002
Λ_b^0 lifetime uncertainty	0.001
Sum in quadrature	0.014

- Consistent with weakly decaying particle

NEW: $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

[LHCb-PAPER-2018-026 in prep.]

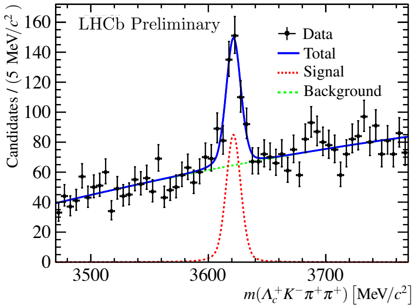


- Latest search: $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ using 1.7 fb^{-1} in Run II
- Measure both mass and ratio of BFs

$$\mathcal{R}(\mathcal{B}) = \frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \times \mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+) \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)}$$

$$m(\Xi_{cc}^{++}) = 3620.6 \pm 1.5(stat) \pm 0.4(syst) \pm 0.3(\Xi_c^+) \mathrm{MeV}/c^2$$

$$\mathcal{R}(\mathcal{B}) = 0.035 \pm 0.009(stat) \pm 0.003(syst)$$



Mixing & CPV

Mixing and CPV

Mixing in a Nutshell

- Mixing in Neutral Mesons: mass≠flavor eigenstates
- Mass Eigenstates: $|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$, $|p|^2 + |q|^2 = 1$

$x = \frac{m_2 - m_1}{\Gamma}$, $y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$, $\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$

CP Violation

- Direct CPV: $\left|\frac{\overline{\mathcal{A}}_{\overline{f}}}{\mathcal{A}_f}\right| \neq 1$

$\mathcal{A}_f = \langle f|\mathcal{H}|D\rangle, \overline{\mathcal{A}}_{\overline{f}} = \langle \overline{f}|\mathcal{H}|\overline{D}\rangle$

- CPV in Mixing: $\left|\frac{q}{p}\right| \neq 1$

Weak Phase: $\phi = \arg\left(\frac{q}{p}\right) \neq 0$

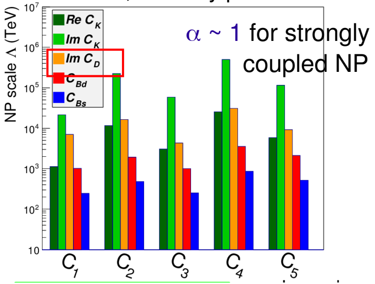
- CPV in Interference between Mixing and Decay:

$\arg\left(\frac{q}{p}\frac{\overline{\mathcal{A}}_f}{\mathcal{A}_f}\right) \neq 0$

Why care?

- Only up-type quark system with mixing
- No CPV seen in this sector yet, though expected at $\mathcal{O}(10^{-3})$ in SM
- Puts indirect constraints on BSM physics

Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase



From Marcella Bona, EPS 2017,

Mixing and CPV in $D^0 \to K^+\pi^-$

[Phys. Rev. D 97, 031101(R)]

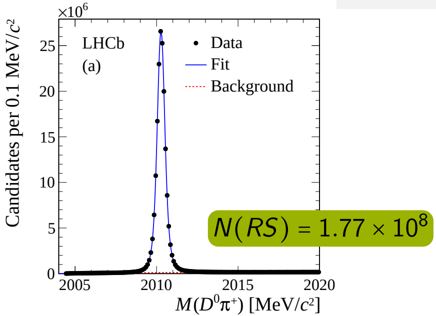
- Restricting to $D^0 \to K\pi$, time dependence of WS/RS ratio

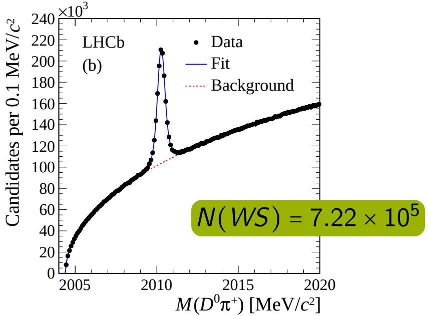
$$\frac{\mathrm{WS}^{\pm}(t)}{\mathrm{RS}^{\pm}(t)} \equiv R^{\pm}(t) \approx R_D^{\pm} + \sqrt{R_D^{\pm}}\, y'^{\pm}\Gamma t + \frac{(x'^{\pm})^2 + (y'^{\pm})^2}{4}(\Gamma t)^2$$

$$x'^{\pm} = \left(+\left|\frac{q}{p}\right|, -\left|\frac{p}{q}\right|\right) \times \left(x'\cos\phi \pm y'\sin\phi\right)$$

$$y'^{\pm} = \left(+\left|\frac{q}{p}\right|, -\left|\frac{p}{q}\right|\right) \times \left(x'\sin\phi \mp y'\cos\phi\right)$$

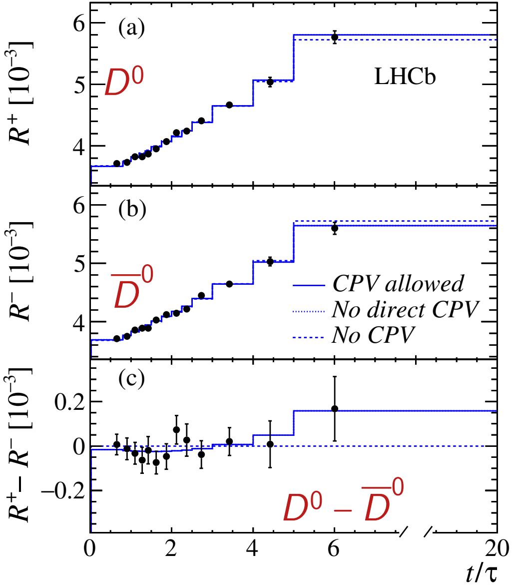
- Three fits:
  1. No CPV$\to$ $R^+ = R^-$, $x'^+ = x'^-$, $y'^+ = y'^-$
  2. No Direct CPV $\to$ $R^+ = R^-$
  3. All CPV allowed
- Use prompt $D^{*+} \to D^0\pi_s^+$, updated with Run I + 2015 + 2016 Data
- Detector asymmetries, peaking backgrounds included in the fit





Mixing and CPV in $D^0 \to K^+\pi^-$

[Phys. Rev. D 97, 031101(R)]



- No evidence of CPV
- Precision increased by a factor of 2 w.r.t. Run I analysis

Results $[10^{-3}]$ / Correlations

Direct and indirect CP violation

Parameter	Value	R_D^+	y'^+	$(x'^+)^2$	R_D^-	y'^-	$(x'^-)^2$
R_D^+	$3.454 \pm 0.040 \pm 0.020$	1.000	−0.935	0.843	−0.012	−0.003	0.002
y'^+	$5.01 \pm 0.64 \pm 0.38$		1.000	−0.963	−0.003	0.004	−0.003
$(x'^+)^2$	$0.061 \pm 0.032 \pm 0.019$			1.000	0.002	−0.003	0.003
R_D^-	$3.454 \pm 0.040 \pm 0.020$				1.000	−0.935	0.846
y'^-	$5.54 \pm 0.64 \pm 0.38$					1.000	−0.964
$(x'^-)^2$	$0.016 \pm 0.033 \pm 0.020$						1.000

No direct CP violation

Parameter	Value	R_D	y'^+	$(x'^+)^2$	y'^-	$(x'^-)^2$
R_D	$3.454 \pm 0.028 \pm 0.014$	1.000	−0.883	0.745	−0.883	0.749
y'^+	$5.01 \pm 0.48 \pm 0.29$		1.000	−0.944	0.758	−0.644
$(x'^+)^2$	$0.061 \pm 0.026 \pm 0.016$			1.000	−0.642	0.545
y'^-	$5.54 \pm 0.48 \pm 0.29$				1.000	−0.946
$(x'^-)^2$	$0.016 \pm 0.026 \pm 0.016$					1.000

No CP violation

Parameter	Value	R_D	y'	x'^2
R_D	$3.454 \pm 0.028 \pm 0.014$	1.000	−0.942	0.850
y'	$5.28 \pm 0.45 \pm 0.27$		1.000	−0.963
x'^2	$0.039 \pm 0.023 \pm 0.014$			1.000

$D^0 \to K_s^0 K_s^0$

[LHCb-PAPER-2018-012 in prep.]

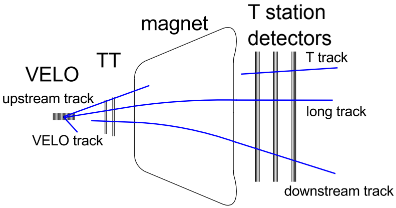
- "Discovery mode" with potentially large direct CPV. $a_{CP}^{dir} \leq 1.1\%$ for $D^0 \to K_s^0 K_s^0$(PRD 92, 054036 (2015))
- Measurement of CP asymmetry requires cancellation of detection/production asymmetries

$$\Delta A_{CP} = A_{CP}(D^0 \to K_s^0 K_s^0) - A_{CP}(D^0 \to K^+ K^-)$$
$$= A_{raw}(D^0 \to K_s^0 K_s^0) - A_{raw}(D^0 \to K^+ K^-)$$

- $K_s^0 \to \pi\pi$ has a significant lifetime, many decays after VELO

→ Separate into samples of LL (both K_s^0 decay in VELO) and LD (one does not)

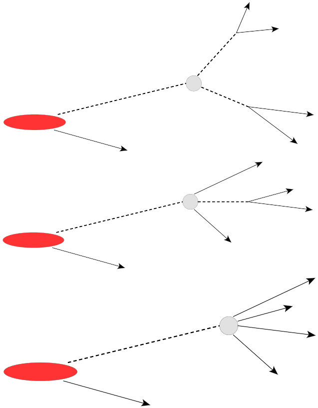
- Extract A_{raw} separately for MagUp/Down, Signal and control channels and LL/LD

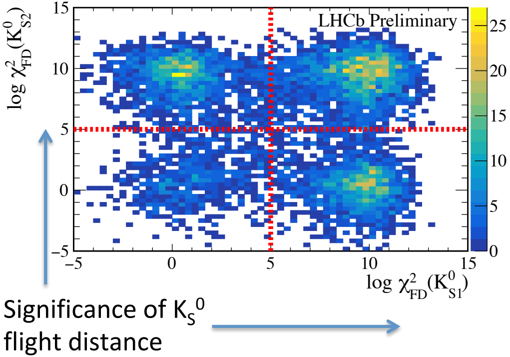


$D^0 \to K_s^0 K_s^0$

[LHCb-PAPER-2018-012 in prep.]

- Need to separate decays of interest from backgrounds
- $D^0 \to K_s^0(\to \pi^+\pi^-)K_s^0(\to \pi^+\pi^-)$ looks alot like $D^0 \to K_s^0\pi^+\pi^-$ and $D^0 \to \pi^+\pi^-\pi^+\pi^-$

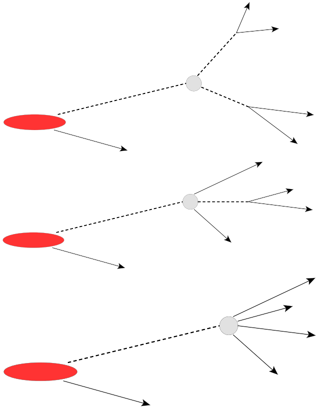


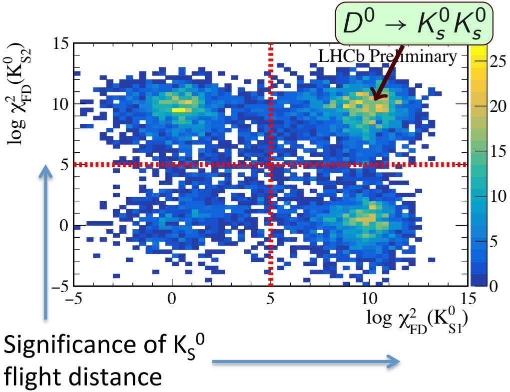


$D^0 \to K_s^0 K_s^0$

[LHCb-PAPER-2018-012 in prep.]

- Need to separate decays of interest from backgrounds
- $D^0 \to K_s^0(\to \pi^+\pi^-)K_s^0(\to \pi^+\pi^-)$ looks alot like $D^0 \to K_s^0\pi^+\pi^-$ and $D^0 \to \pi^+\pi^-\pi^+\pi^-$

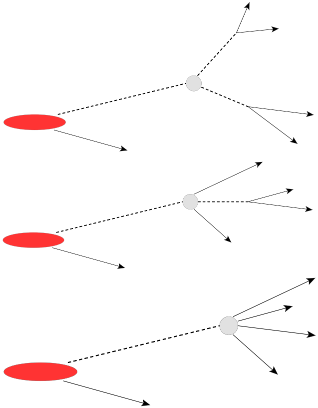


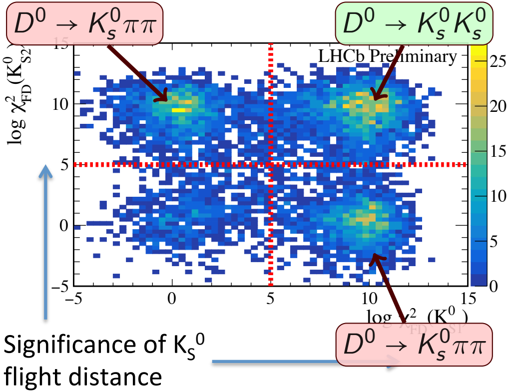


$D^0 \to K_s^0 K_s^0$

[LHCb-PAPER-2018-012 in prep.]

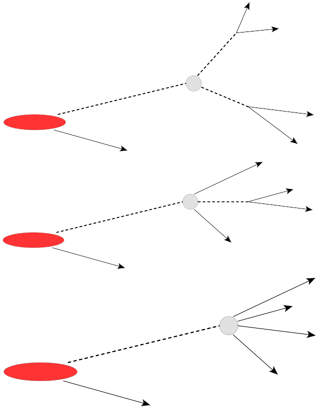
- Need to separate decays of interest from backgrounds
- $D^0 \to K_s^0(\to \pi^+\pi^-)K_s^0(\to \pi^+\pi^-)$ looks alot like $D^0 \to K_s^0\pi^+\pi^-$ and $D^0 \to \pi^+\pi^-\pi^+\pi^-$

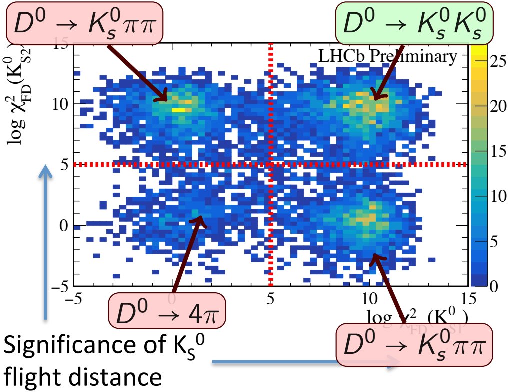




$D^0 \to K_s^0 K_s^0$

- Need to separate decays of interest from backgrounds
- $D^0 \to K_s^0(\to \pi^+\pi^-)K_s^0(\to \pi^+\pi^-)$ looks alot like $D^0 \to K_s^0\pi^+\pi^-$ and $D^0 \to \pi^+\pi^-\pi^+\pi^-$





$D^0 \to K_s^0 K_s^0$

[LHCb-PAPER-2018-012 in prep.]

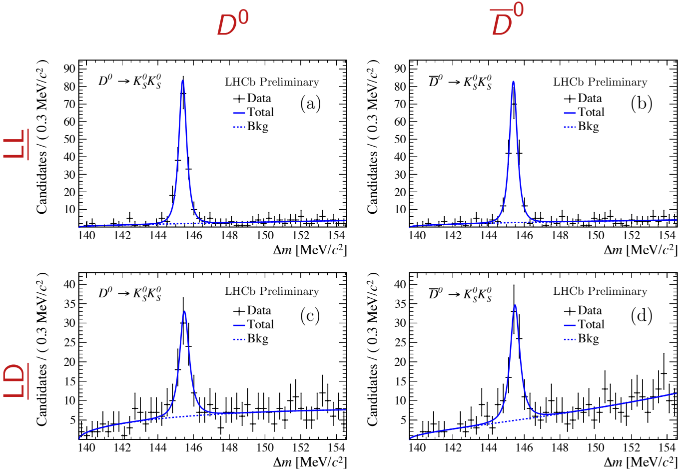
- Use $D^{*+} \to D^0\pi^+$ with Run II data (2015+2016)
- Example fits: Δm for Mag Up category
- Yields: $\sim 1.3M D^0 \to K^+K^-$, $\sim 150-400 D^0 \to K_s^0 K_s^0$ per sample

$$A_{CP}(K_s^0 K_s^0) = (+4.2 \pm 3.4 \pm 1.0)\%$$

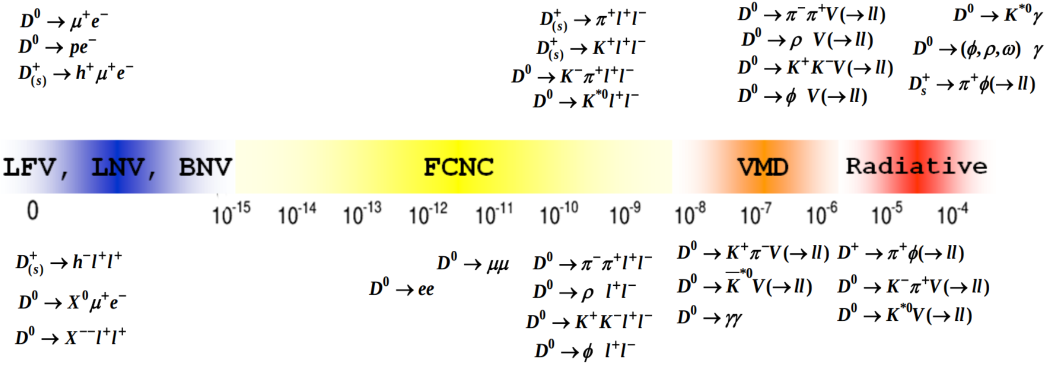
Combining with Run 1

$$A_{CP}(K_s^0 K_s^0) = (+2.0 \pm 2.9 \pm 1.0)\%$$

- No sign of direct CPV, not yet competitive with Belle



Rare Decays

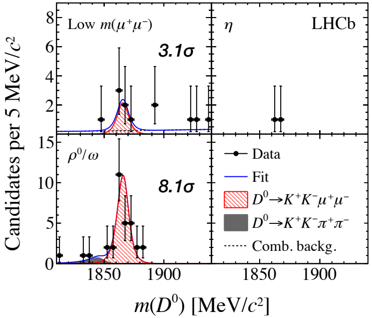

$D^0 \to \mu^+ e^-$
$D^0 \to p e^-$
$D^+_{(s)} \to h^+ \mu^+ e^-$
$D^+_{(s)} \to \pi^+ l^+ l^-$
$D^+_{(s)} \to K^+ l^+ l^-$
$D^0 \to K^- \pi^+ l^+ l^-$
$D^0 \to K^{*0} l^+ l^-$
$D^0 \to \pi^- \pi^+ V(\to ll)$
$D^0 \to \rho \; V(\to ll)$
$D^0 \to K^+ K^- V(\to ll)$
$D^0 \to \phi \; V(\to ll)$
$D^0 \to K^{*0} \gamma$
$D^0 \to (\phi, \rho, \omega) \; \gamma$
$D^+_s \to \pi^+ \phi(\to ll)$
LFV, LNV, BNV
FCNC
VMD
Radiative
0
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
$D^+_{(s)} \to h^- l^+ l^+$
$D^0 \to X^0 \mu^+ e^-$
$D^0 \to X^{--} l^+ l^+$
$D^0 \to \mu\mu$
$D^0 \to ee$
$D^0 \to \pi^- \pi^+ l^+ l^-$
$D^0 \to \rho \; l^+ l^-$
$D^0 \to K^+ K^- l^+ l^-$
$D^0 \to \phi \; l^+ l^-$
$D^0 \to K^+ \pi^- V(\to ll)$
$D^0 \to \overline{K}^{*0} V(\to ll)$
$D^0 \to \gamma\gamma$
$D^+ \to \pi^+ \phi(\to ll)$
$D^0 \to K^- \pi^+ V(\to ll)$
$D^0 \to K^{*0} V(\to ll)$

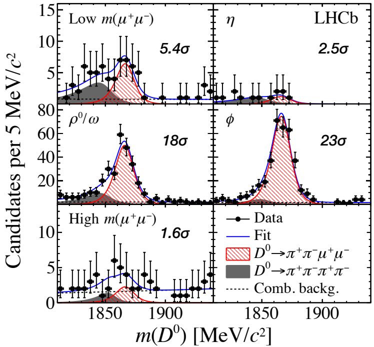
Rare Charm Decays

- Owing to the huge charm samples and excellent efficiency with muons, LHCb has been able to, with only Run I data
- Observe $D^0 \to hh\mu\mu$ decays [PRL 119, 181805 (2017)]

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$
$$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$$

- Rarest charm hadron decay ever observed





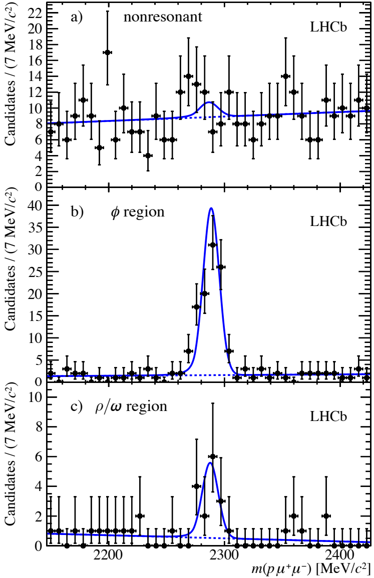
Rare Charm Decays

- Owing to the huge charm samples and excellent efficiency with muons, LHCb has been able to, with only Run I data
- Search for $\Lambda_c^+ \to p\mu\mu$[PRD 97, 091101 (2018)]
  - Upper-limit on non-resonant component

$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 9.6\times10^{-8}(95\%\text{CL})$$

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

$$\mathcal{B}(\Lambda_c^+ \to p[\mu\mu]_{\rho/\omega}) = (9.4\pm3.2\pm1.0\pm2.0)\times10^{-4}$$

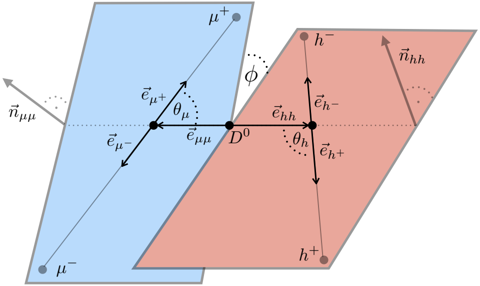


- Use Run 1+2 (2011-2016) $D^0 \to hh\mu\mu$ sample to probe asymmetries

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

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

$$A_{CP} = \frac{\Gamma(D^0 \to hh\mu\mu) - \Gamma(\overline{D}^0 \to hh\mu\mu)}{\Gamma(D^0 \to hh\mu\mu) + \Gamma(\overline{D}^0 \to hh\mu\mu)}$$



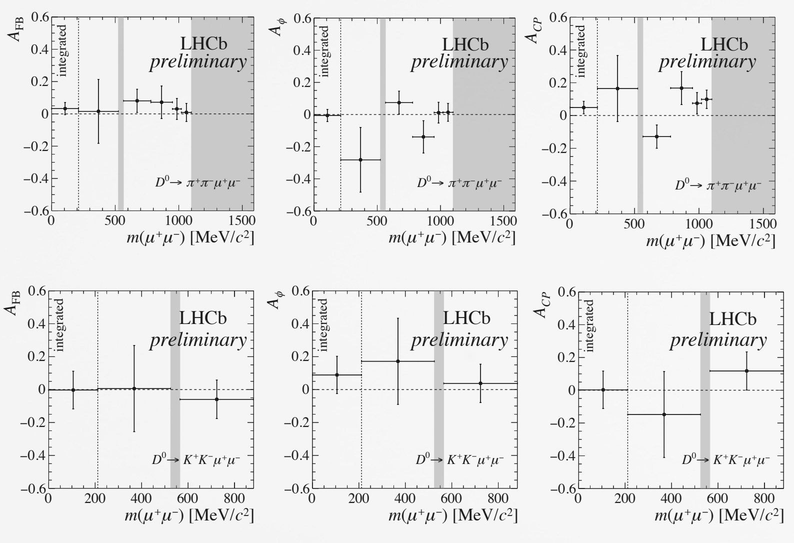
- Should be a null test of the SM, but could have $\mathcal{O}$(few%) predictions for some NP models

JHEP 1304 135 (2013),PRD 87 054026 (2013),PRD 93, 074001 (2016),1805.08516

- For CPV search, use $D^{*+} \to D^0\pi^+$,

$A_{CP}(D^0 \to hh\mu\mu) = A_{raw}(D^0 \to hh\mu\mu) - A_{raw}(D^0 \to KK) + A_{CP}(D^0 \to KK)$

Angular asymmetries in $D^0 \to hh\mu\mu$

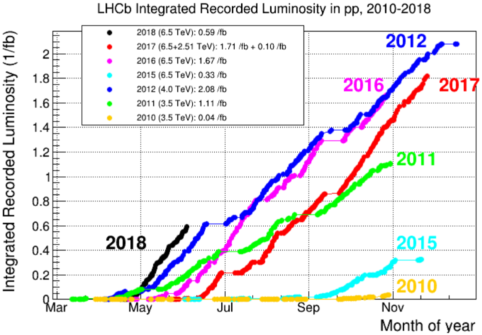


$$A_{FB}(D^0 \to \pi\pi\mu\mu) = (3.3 \pm 3.7 \pm 0.6)\%$$
$$A_\phi(D^0 \to \pi\pi\mu\mu) = (-0.6 \pm 3.7 \pm 0.6)\%$$
$$A_{CP}(D^0 \to \pi\pi\mu\mu) = (4.9 \pm 3.8 \pm 0.7)\%$$
$$A_{FB}(D^0 \to KK\mu\mu) = (0 \pm 11 \pm 2)\%$$
$$A_\phi(D^0 \to KK\mu\mu) = (9 \pm 11 \pm 1)\%$$
$$A_{CP}(D^0 \to KK\mu\mu) = (0 \pm 11 \pm 2)\%$$

- All consistent with zero and SM expectations, no $m(\mu\mu)$ dependence

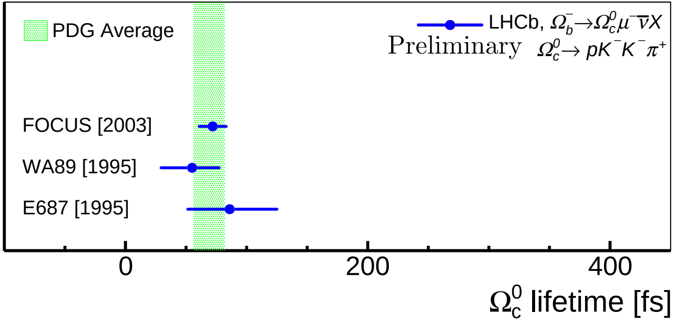
Conclusions

- LHCb is a charm factory
- Lots of interesting physics results already available
- 2018 running is ongoing with efficient datataking
- Already 7.5 fb^{-1} on tape from 2011-2018
- Expect 9 fb^{-1} on tape by end of Run II
- Expect many new searches and updates soon!
- At the end of 2019, LHCb will completely upgrade the detector
- Many exciting years of physics to come

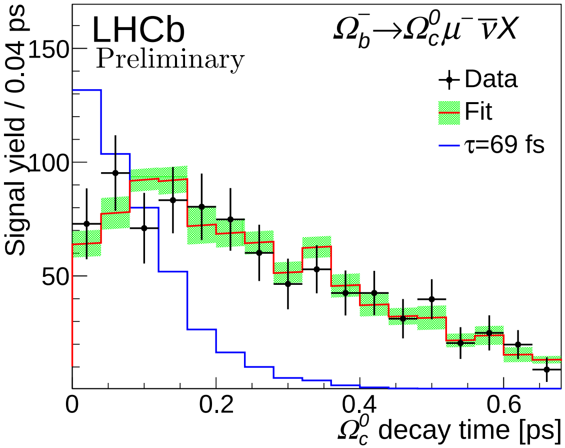


Backup Slides

Ω_c^0 Lifetime comparisons



- Comparison of lifetime in MC with τ = 69fs with data



Some possible conclusions on the Ω_c^0 lifetime

- Most theory/pheno papers expect Ω_c^0 lifetime to be the shortest, due to large constructive PI between s-quarks in final state. This result turns that expectation upside down!
  - At $\mathcal{O}(1/m_c^2)$: poor quantitative understanding of spin-spin interaction?
  - At $\mathcal{O}(1/m_c^3)$: poor quantitative understanding of PI or W-exchange processes?
- Could re-ignite further theoretical work to understand baryon structure, and the impact on their treatment in the HQE.
- Other charm baryon lifetimes to follow in the coming months.

E687 Result on Ω_c^0 lifetime [PLB 357 (1995) 678-684]

E687 Collaboration / Physics Letters B 357 (1995) 678–684

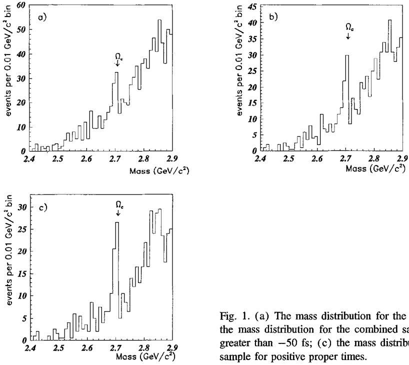


Fig. 1. (a) The mass distribution for the combined sample; (b) the mass distribution for the combined sample for proper times greater than −50 fs; (c) the mass distribution for the combined sample for positive proper times.

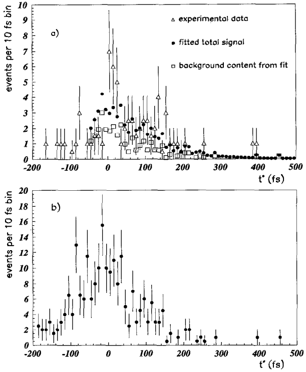


Fig. 2. The observed proper time (t^*) distributions for the combined sample: (a) in the signal region. The solid circles are the total signal obtained from the fit while the squares are the background contribution. Note that the fit results start from $t^* > -50$ fs, corresponding to the final choice of t^*_{cut} (see text); (b) in the sidebands. (The sizes of the sidebands are given in the text).

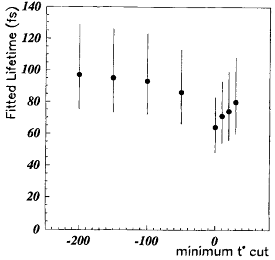


Fig. 4. Lifetime of the Ω_c^0 for different minimum t^* cuts.

WA89 Result on Ω_c^0 lifetime[PLB 358:151-161,1995]

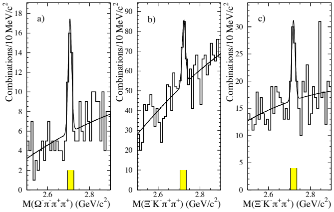


Figure 3: Mass distributions for three different final states: a) $\Omega^-\pi^+\pi^-\pi^+$, b) $\Xi^-K^-\pi^+\pi^+$ from carbon, c) $\Xi^-K^-\pi^+\pi^+$ from all targets with positively RICH identified kaon. The shaded region denotes the signal band.

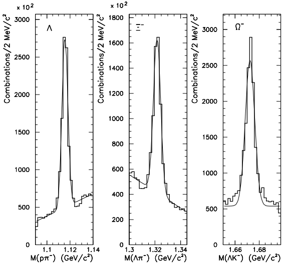


Figure 2: Examples for mass distributions of reconstructed strange particles.

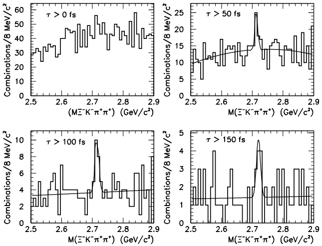


Figure 6: invariant mass distributions for the $\Xi^-K^-\pi^+\pi^+$ sample with positively identified kaons using different lifetime cuts for the charm candidates.

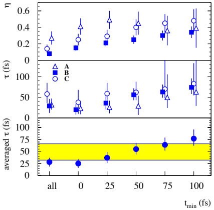


Figure 7: Results of the likelihood fits (see text) for the different samples and their dependence on the lower decay time cut t_{min} used in the fit. The shaded area represents the size of the full systematic error. Sample A) denotes $\Omega^-\pi^+\pi^-\pi^+$, sample B) $\Xi^-K^-\pi^+\pi^+$ from the carbon target and sample C) $\Xi^-K^-\pi^+\pi^+$ with identified K^-.

FOCUS Result on Ω_c^0 lifetime[PLB 561:41-48,2003]

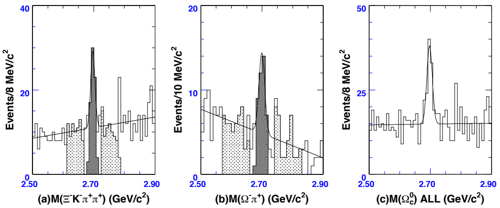


FIG. 1: Invariant mass distributions for Ω_c^0 candidates: (a) Reconstructed mass of $\Xi^- K^- \pi^+ \pi^+$. There are 38 ± 9 events at a mass of 2696.5 ± 1.9 MeV/c^2. (b) Reconstructed mass of $\Omega^- \pi^+$. There are 23 ± 7 events at a mass of 2699.4 ± 3.4 MeV/c^2. (c) Combined invariant mass distribution. There are 64 ± 14 events at a mass of 2697.5 ± 2.2 MeV/c^2. We define the signal region (hatched area) to be within $2\,\sigma$ of the fitted mass value and the two sideband regions (dotted area) are 4–12 σ from the fitted mass value.

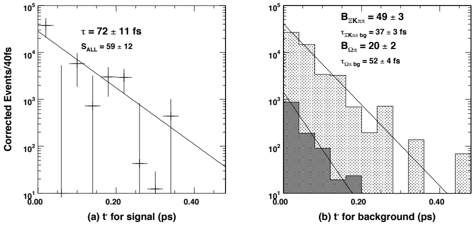


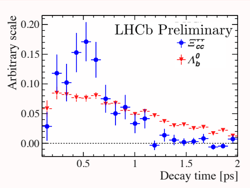
FIG. 3: (a) The corrected t' distribution with the lifetime fit function for the combined signal. (b) The t' distributions of expected backgrounds in the signal band for each mode; the dark region is for $\Xi^- K^- \pi^+ \pi^+$ and the light one is for $\Omega^- \pi^+$. Lines show the lifetime fitting functions for signal and background distributions. The lifetime fit finds 59 ± 12 signal events rather than 64 ± 14 due to the 2σ mass window used.

NEW: Ξ_{cc} lifetime

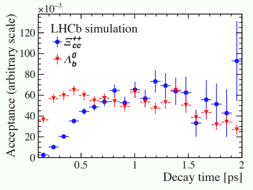
- Measure $\tau(\Xi_{cc}^{++})$ with efficiencies given relative to control channel $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$

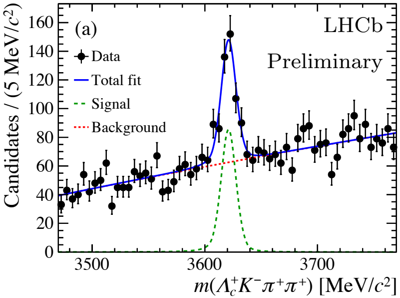
$$f_{\Xi_{cc}^{++}}(t) = H_{\Lambda_b^0}(t) \times \frac{\epsilon_{\Xi_{cc}^{++}}(t)}{\epsilon_{\Lambda_b^0}(t)} \times \exp\left(\frac{t}{\tau(\Lambda_b^0)} - \frac{t}{\tau(\Xi_{cc}^{++})}\right)$$

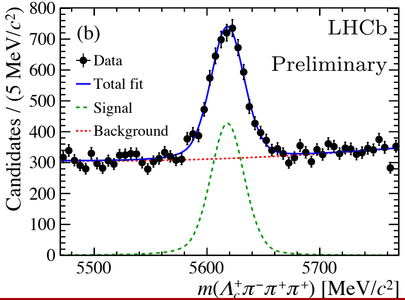
Background Subtracted $\tau(\Lambda_b^0)$



Decay-time acceptance ratio







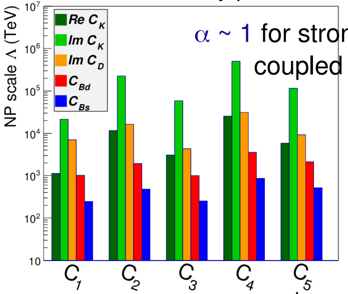
Why is it important?

Updates from UTfit

results from the Wilson coefficients

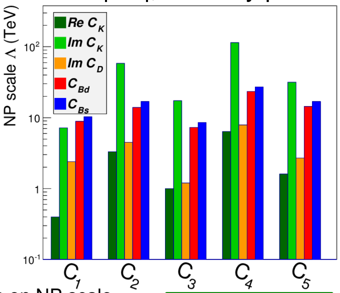
Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase

NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$, $F_i \sim |F_{SM}|$, arbitrary phase



$\alpha \sim 1$ for strongly coupled NP

$\Lambda > 5.0\ 10^5$ TeV



$\Lambda > 114$ TeV

Lower bounds on NP scale (in TeV at 95% prob.)

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

$\Lambda > 1.5\ 10^4$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

$\Lambda > 3.4$ TeV

for lower bound for loop-mediated contributions, simply multiply by α_s ($\sim$ 0.1) or by α_W ($\sim$ 0.03).

Marcella Bona

22

- From Marcella Bona, EPS 2017,
- $C_i(\Lambda) = \frac{L \times F_i}{\Lambda^2}$
- Use $F_i \simeq L \simeq 1$
  bounds on C_i
  give lower bound on Λ

$$\mathcal{H}_{\rm eff}^{\Delta F=2} = \sum_{i=1}^{5} C_i Q_i^{q_j q_k} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{q_j q_k}$$

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha} \gamma_\mu q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} \gamma^\mu q_{iL}^{\beta} \\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jR}^{\beta} q_{iL}^{\beta} \\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jR}^{\beta} q_{iL}^{\alpha} \\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} q_{iR}^{\beta} \\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jL}^{\beta} q_{iR}^{\alpha}
\end{aligned}$$

Definitions from [0707.0636]