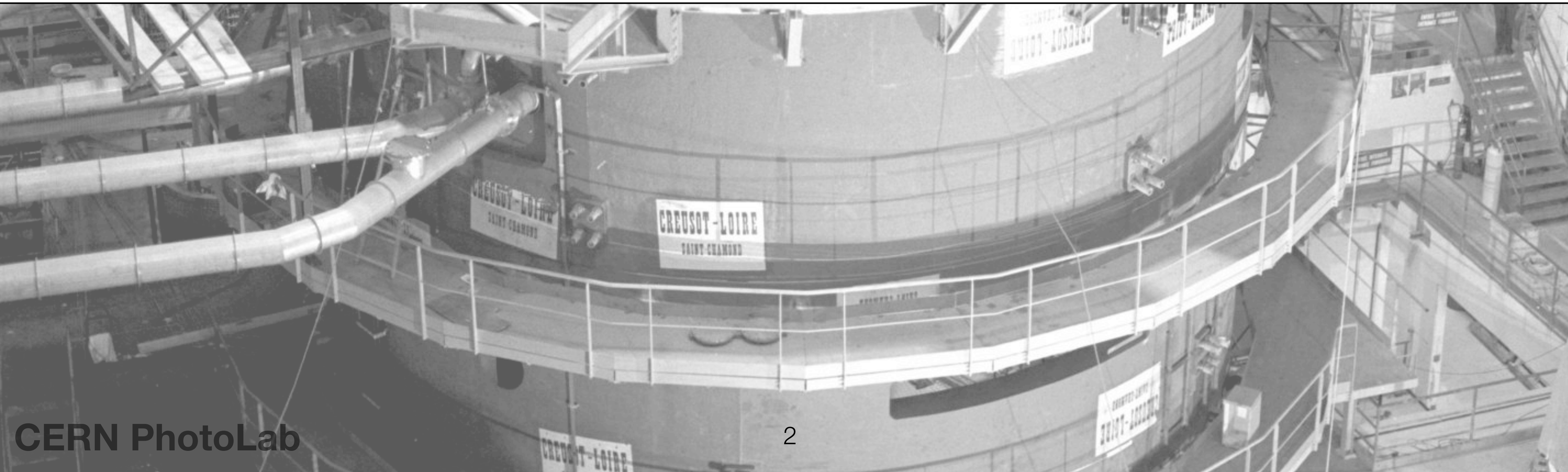
Open-charm hadrons: production and properties

Daniel O'Hanlon, *on behalf of the LHCb collaboration*

ICHEP 2018, Seoul

Production



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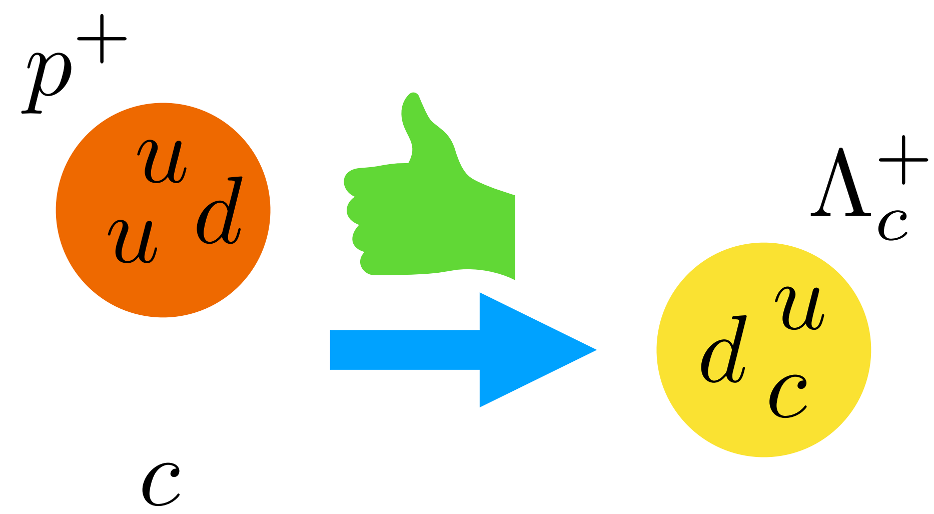
Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

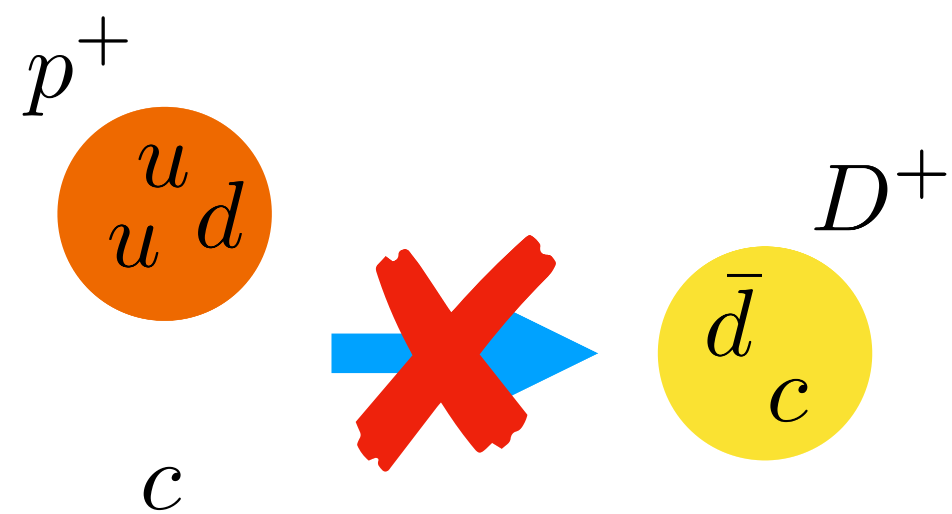
arXiv:1805.09869 (Submitted to JHEP)

- Assumed for most charm production asymmetries:

  Arise from ability of charm quarks to form charm baryons with **proton** valence quarks



  …but **not** charm mesons



- This results in a different kinematic distribution between charged conjugate hadrons

Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

So what happens if we have a meson that contains none of the proton valence quarks?

D_s^+ production asymmetry:

$$A_{\mathrm{P}}(D_s^+) = \frac{\sigma(D_s^+) - \sigma(D_s^-)}{\sigma(D_s^+) + \sigma(D_s^-)}$$

Where D_s^+ is reconstructed as $D_s^+ \to \phi(K^+K^-)\pi^+$, and $A_{\mathrm{raw}} = \dfrac{N(D_s^+) - N(D_s^-)}{N(D_s^+) + N(D_s^-)}$

such that:

$$A_{\mathrm{P}}(D_s^+) = \frac{1}{1 - f_{\mathrm{bkg}}}(A_{\mathrm{raw}} - A_{\mathrm{D}} - f_{\mathrm{bkg}} A_{\mathrm{P}}(B))$$

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Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

$$A_{\mathrm{P}}(D_s^+) = \frac{1}{1 - f_{\mathrm{bkg}}}(A_{\mathrm{raw}} - A_{\mathrm{D}} - f_{\mathrm{bkg}} A_{\mathrm{P}}(B))$$

Fraction of non-prompt D_s^+ decays (from b-hadrons) → f_{bkg}

Detection asymmetries → A_{D}

Production asymmetry of b-hadrons → $A_{\mathrm{P}}(B)$

$f_{\mathrm{bkg}} = (4.12 \pm 1.23)\%$ → Determined from simulation, known cross sections and branching fractions

$A_{\mathrm{D}} = A^{\pi}_{\mathrm{track}} + A^{KK}_{\mathrm{track}} + A_{\mathrm{PID}} + A^{\mathrm{software}}_{\mathrm{trigger}} + A^{\mathrm{hardware}}_{\mathrm{trigger}}$ → Data driven corrections

$f_{\mathrm{bkg}} A_{\mathrm{P}} = (0.3 \pm 1.0) \times 10^{-4}$ (7 TeV)
$f_{\mathrm{bkg}} A_{\mathrm{P}} = (1.7 \pm 0.8) \times 10^{-4}$ (8TeV) → From published LHCb production asymmetries

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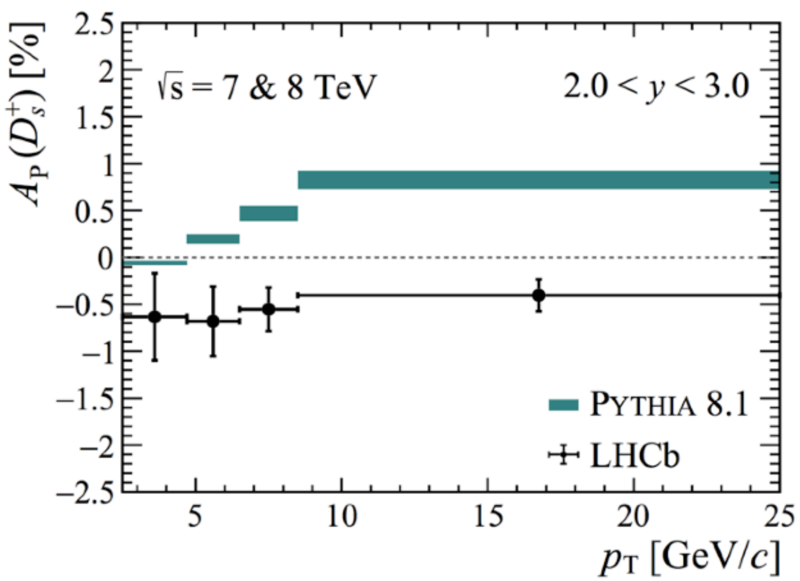
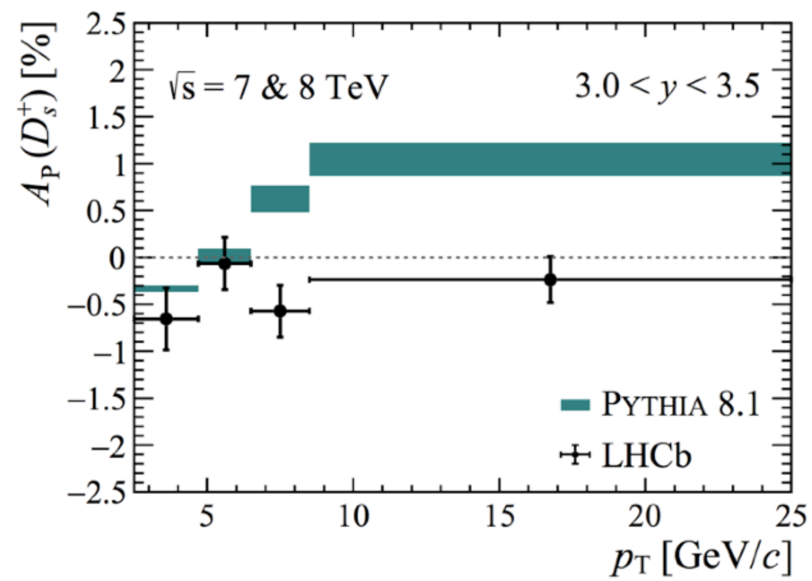
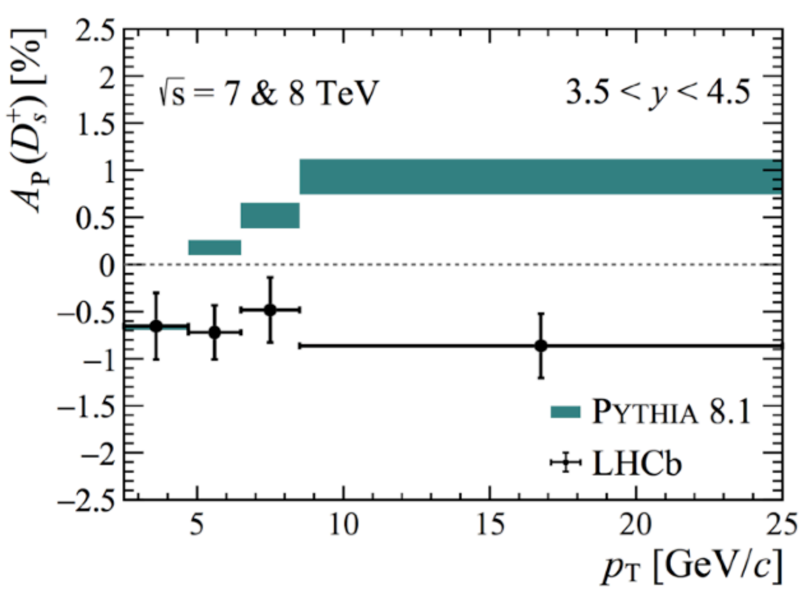
Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV





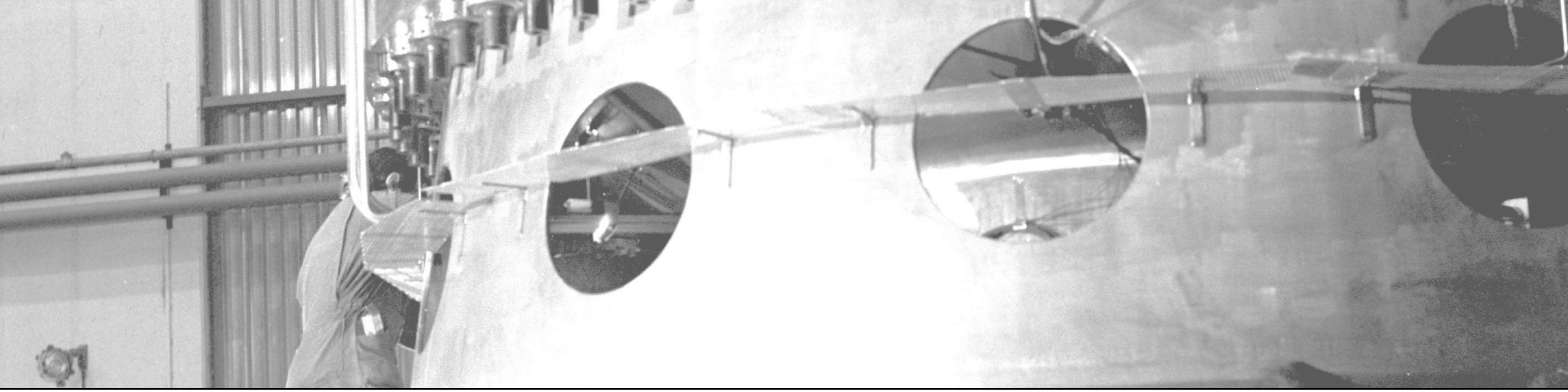


$$A_{\rm P}(D_s^+) = (-0.52 \pm 0.13\ (\text{stat.}) \pm 0.10\ (\text{syst.}))\%$$

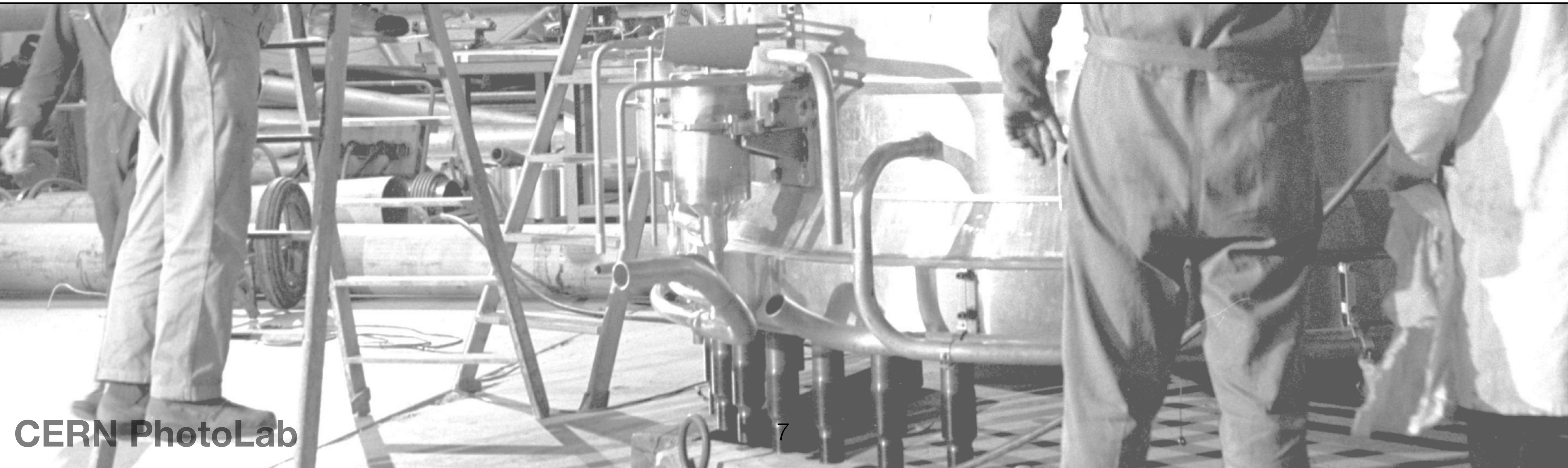
(Averaged over 7 and 8 TeV)

A useful test of non-perturbative QCD, an essential input to LHCb CP violation measurements using D_s^+ decays

arXiv:1805.09869 (Submitted to JHEP)



Properties



Measurement of the Ω_c^0 lifetime

LHCB-PAPER-2018-028 (To be submitted to PRL)

- Compared to charm mesons, charm baryon lifetimes are not well known,

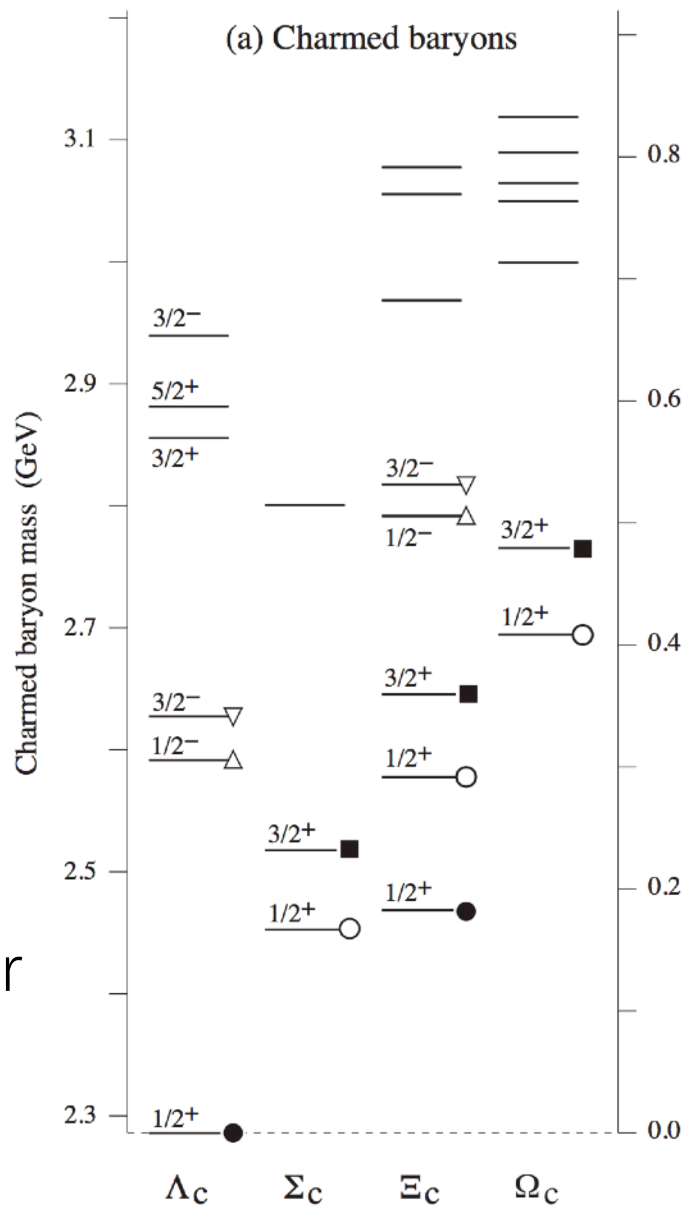
$$\frac{\sigma(\tau_{D^0})}{\tau_{D^0}} \sim 0.4\% \quad \text{vs} \quad \frac{\sigma(\tau_{\Omega_c^0})}{\tau_{\Omega_c^0}} \sim 17\%$$

and are not precisely calculable using HQET due to larger non-perturbative corrections

- Nevertheless, expected that

$$\tau_{\Xi_c^+} > \tau_{\Lambda_c} > \tau_{\Xi_c^0} > \tau_{\Omega_c^0}$$

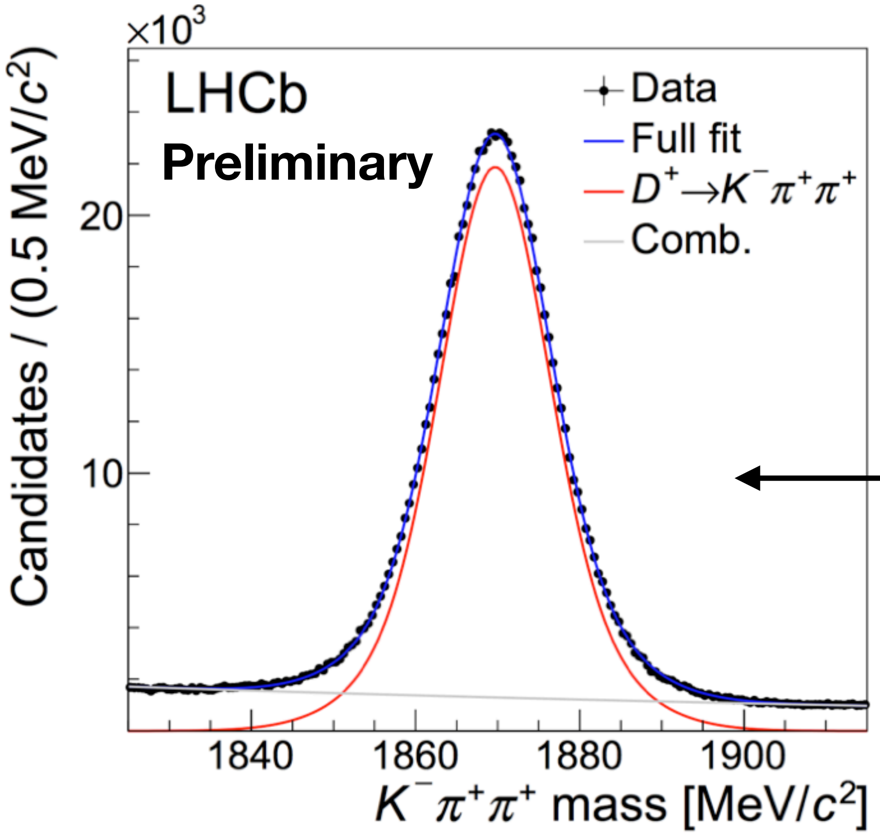
partly due to constructive interference between the spectator s-quark and s-quark in $c \to sW^+$ transition



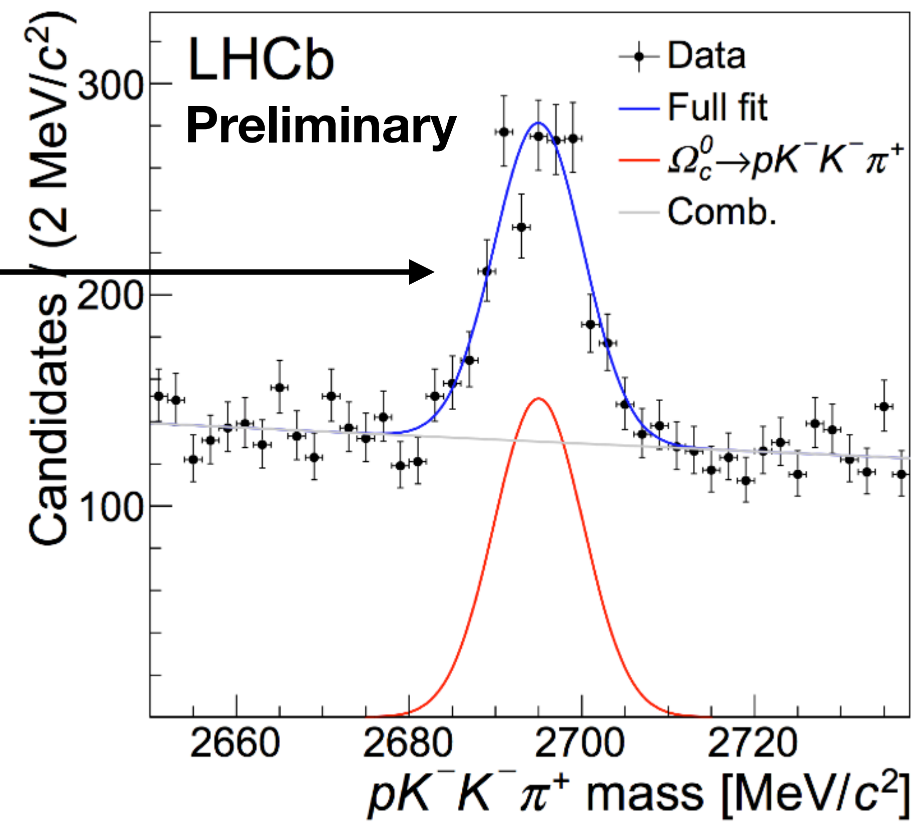
Measurement of the Ω_c^0 lifetime

- Here we measure $\frac{\tau_{\Omega_c^0}}{\tau_{D^+}}$ using semileptonic Ω_b^- and B decays:

$\Omega_b^- \to \Omega_c^0 \mu^- \bar{\nu}_\mu X$
with $\Omega_c^0 \to p K^- K^- \pi^+$



$$\frac{\tau_{\Omega_c^0}}{\tau_{D^+}}$$

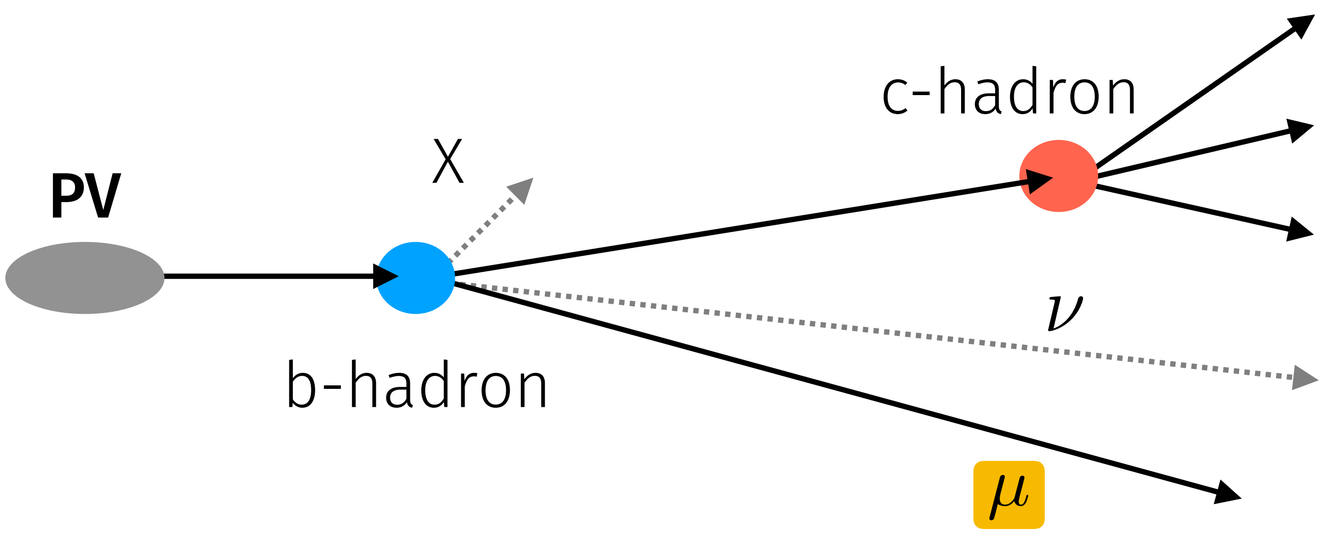


$B \to D^+ \mu^- \bar{\nu}_\mu X$
with $D^+ \to K^- \pi^+ \pi^+$

(~1000 candidates)

Measurement of the Ω_c^0 lifetime

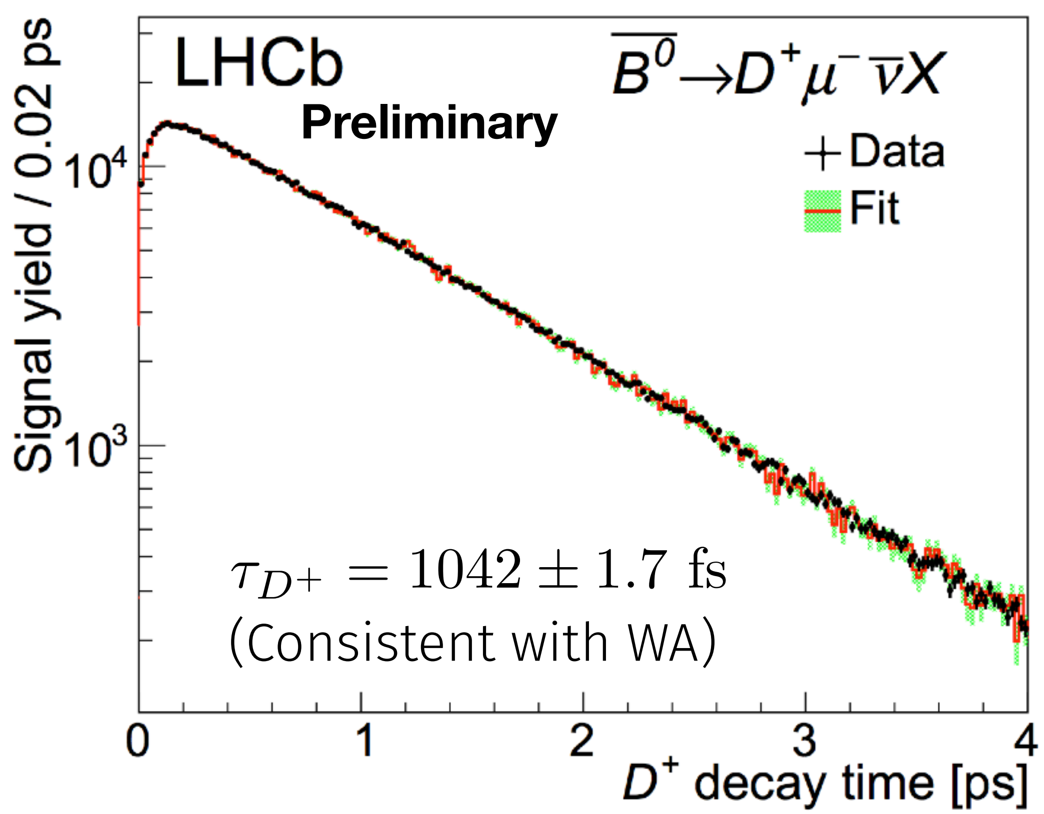
- Decay times of the c-hadrons are determined via the distance between the b and c-hadron decay vertices, and c-hadron momentum

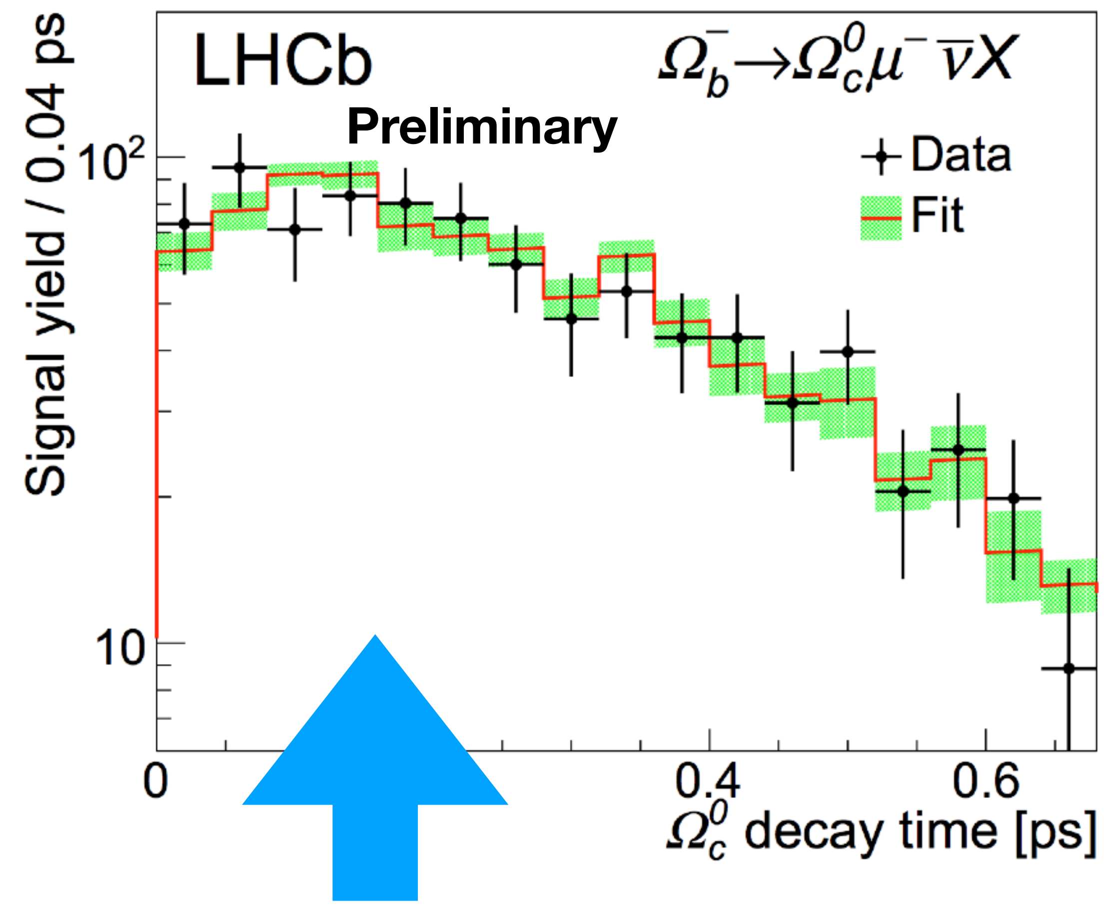


- b-hadron vertex is well determined from the c-hadron and muon trajectories
- c-hadron tracks have large impact parameter to PV thanks to the long b-hadron lifetime

Measurement of the Ω_c^0 lifetime

- **Simultaneous fit** of background subtracted D^+ and Ω_c^0 decay times
- Correction for data/MC discrepancy for vertex locator track reconstruction efficiency → (1.0 ± 0.5) %





$$\tau_{\Omega_c^0} = 268 \pm 24 \pm 10 \pm 2 \text{ fs}$$

LHCB-PAPER-2018-028

Measurement of the Ω_c^0 lifetime

- Backgrounds from:

random $h_c\mu^-$ combinations

$h_b \to h_c\tau^-\bar{\nu}_\tau$ where $\tau^- \to \mu^-\nu_\tau\bar{\nu}_\mu$

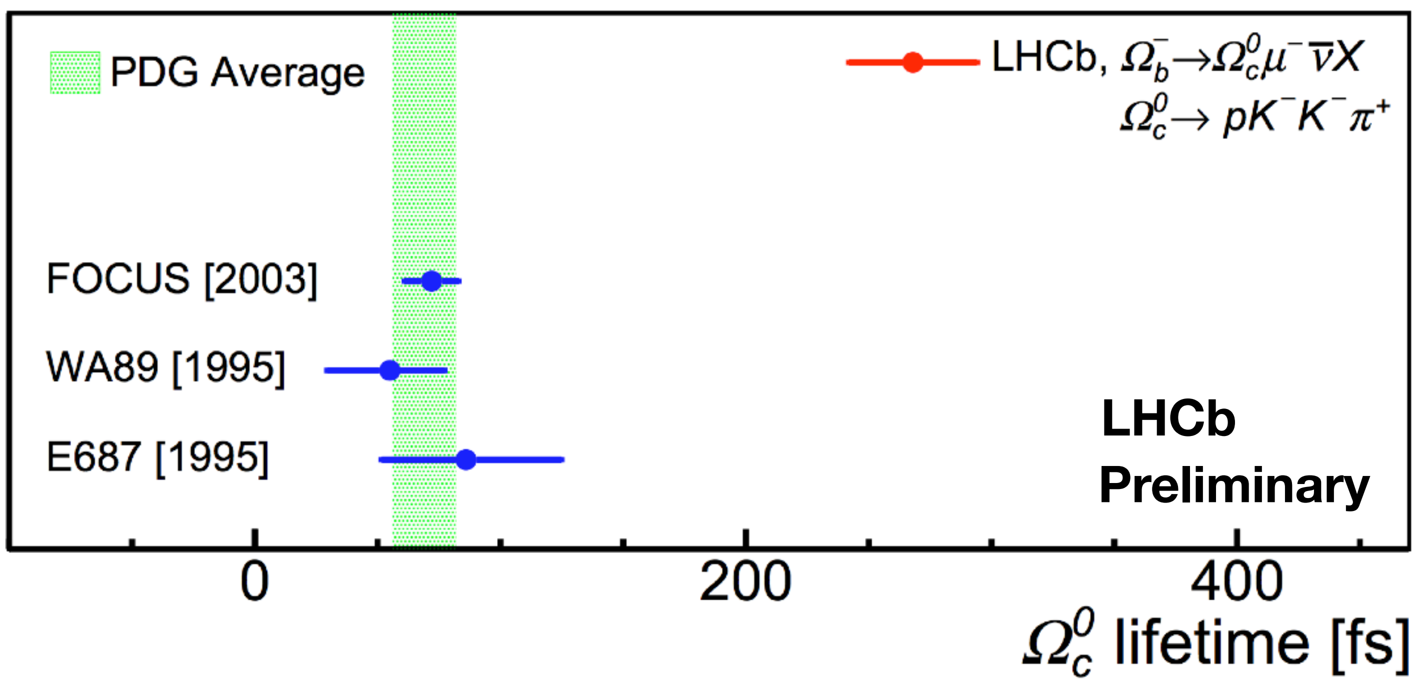
$h_b \to h_c\overline{D}$ where $\overline{D} \to \mu^- X$

contribute 3%, and could lead to a bias as the muon is not produced at the b-hadron decay vertex

- However these have a decay time distribution (for t > 0) similar to the true final state, and contribute similarly to signal and normalisation, resulting in a **partial cancellation**

Measurement of the Ω_c^0 lifetime

- Measurement performed with an order of magnitude more Ω_c^0 candidates than the others listed in the PDG, and the first from a collider experiment
- Results in a lifetime 4x that of the PDG average:



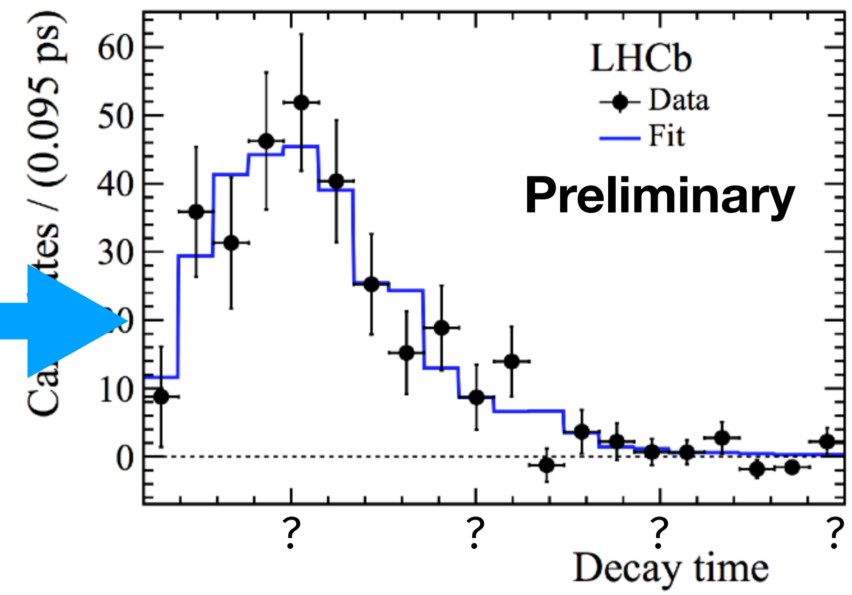
- The corresponding hierarchy is $\tau_{\Xi_c^+} > \tau_{\Omega_c^0} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0}$ which provides new information on the relative roles of the spectator quark and non-perturbative effects in Ω_c^0 decays

Additional measurements

- Lifetime measurement of the Ξ_{cc}^{++} baryon

(see the talk by Jibo He after this one!)

(LHCb-PAPER-2018-028, to be submitted to PRL)

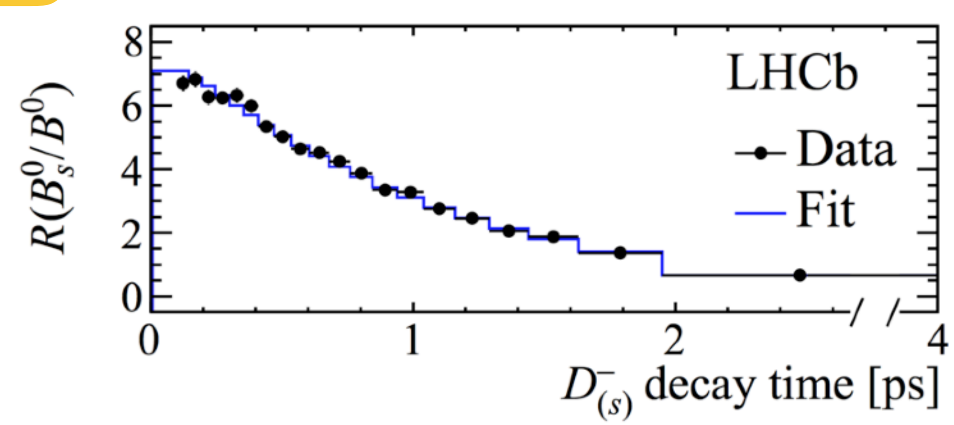


- Lifetime measurement of the D_s^- meson:

$$\tau_{D_s^+} = 0.5064 \pm 0.0030 \text{ (stat)} \pm 0.0017 \text{ (syst)} \pm 0.0017 \ (\tau_D) \text{ ps}$$

→ the most precise from a single experiment

(Phys. Rev. Lett. 119, 101801 (2017), arXiv:1705.03475)



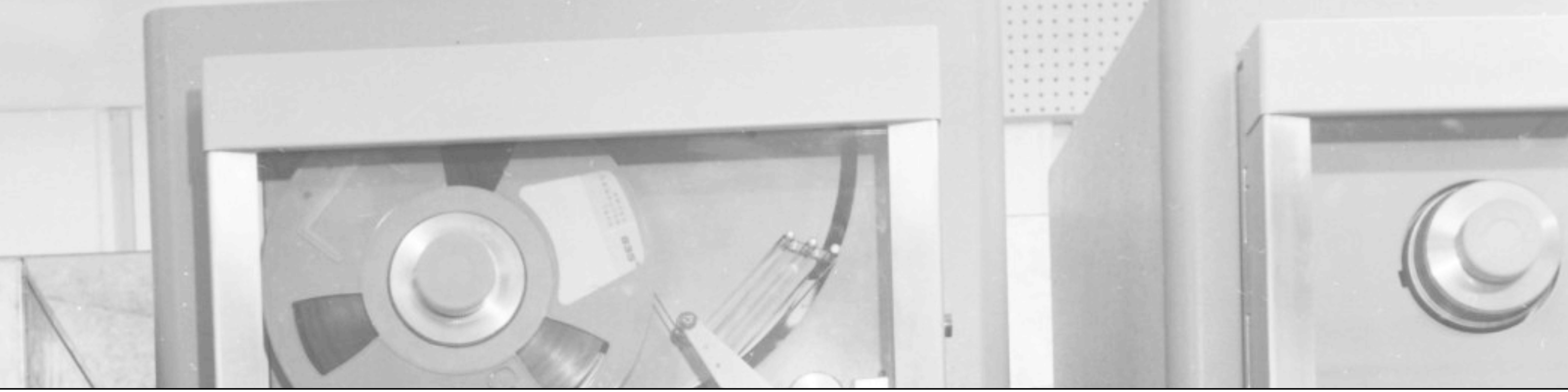
- Prompt charm production cross-sections at 5 TeV

(JHEP06(2017)147, arXiv:1610.02230)

Summary

- Measurement of the D_s^+ meson production asymmetry at 7 and 8 TeV:
  - **Consistent with zero** asymmetry at the 3σ level, no evidence for any kinematical dependence
  - Not well reproduced by Pythia 8.1
  - **A good test of non-perturbative QCD**, and input to future LHCb measurements

- Measurement of Ω_c^0 lifetime:
  - **Inconsistent** with measurements from fixed-target experiments
  - Results in a change in the hierarchy of charm baryon lifetimes
  - Could require reconsideration of role of constructive s-quark interference



Backup

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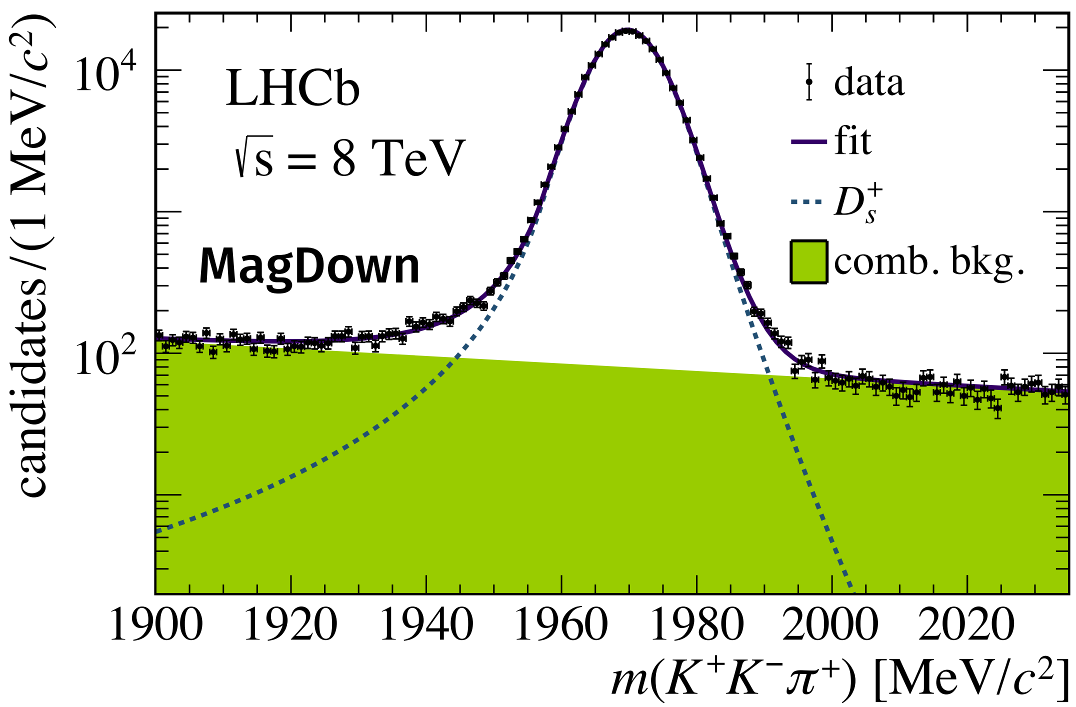
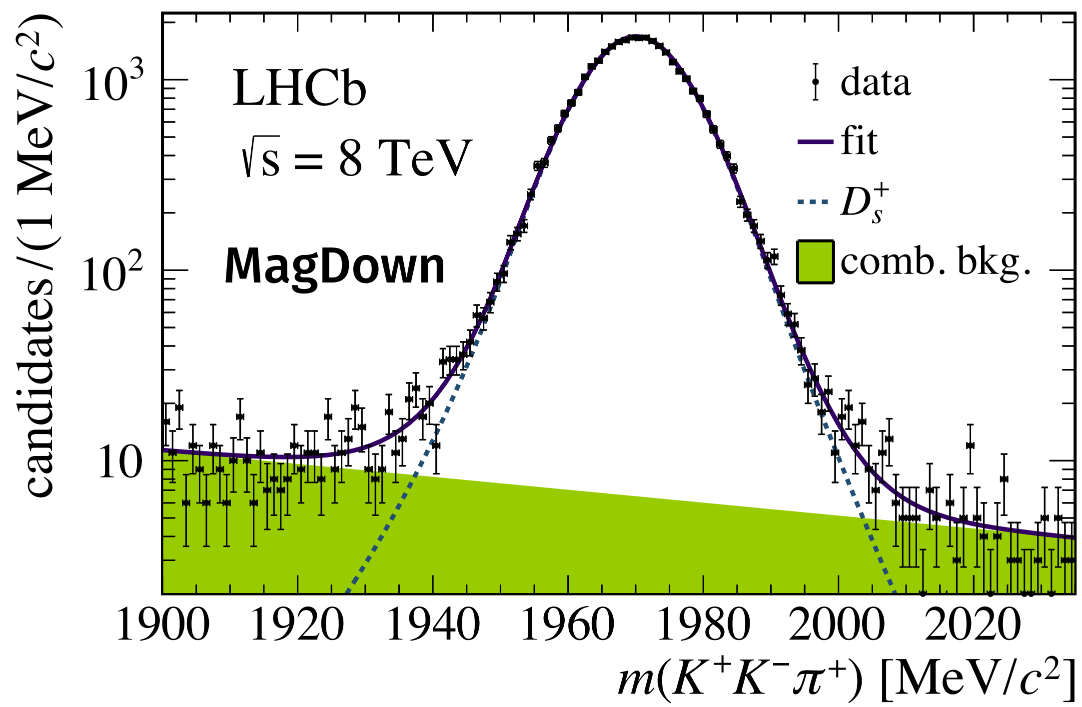
Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

Mass fit projections (8 TeV)



2.0 < y < 3.0
2.5 < p_T < 4.7 GeV



3.5 < y < 4.5
8.5 < p_T < 25.0 GeV

arXiv:1805.09869 (Submitted to JHEP)

Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

$A_{\rm D} = A^{\pi}_{\rm track} + A^{KK}_{\rm track} + A_{\rm PID} + A^{\rm software}_{\rm trigger} + A^{\rm hardware}_{\rm trigger}$ → Data driven corrections

source	$\sqrt{s} = 7\,\text{TeV}$	$\sqrt{s} = 8\,\text{TeV}$
$A_{\rm raw}$	$-0.431 \pm 0.061 \pm 0.006$	$-0.492 \pm 0.034 \pm 0.006$
$A^{\pi}_{\rm track}$	$0.093 \pm 0.096 \pm 0.048$	$-0.026 \pm 0.068 \pm 0.048$
$A^{KK}_{\rm track}$	$0.000 \pm 0.000 \pm 0.030$	$0.000 \pm 0.000 \pm 0.030$
$A_{\rm PID}$	$-0.018 \pm 0.008 \pm 0.012$	$0.008 \pm 0.005 \pm 0.012$
$A^{\rm hardware}_{\rm trigger}$	$0.139 \pm 0.229 \pm 0.066$	$-0.060 \pm 0.115 \pm 0.066$
$A^{\rm software}_{\rm trigger}$	$-0.005 \pm 0.018 \pm 0.033$	$0.026 \pm 0.011 \pm 0.033$
$A_{\rm P}(D_s^+)$	$-0.671 \pm 0.267 \pm 0.095$	$-0.477 \pm 0.145 \pm 0.095$

$A^{KK}_{\rm track}$ arises from non-resonant KK (rather than from $\phi \to K^+K^-$decays)

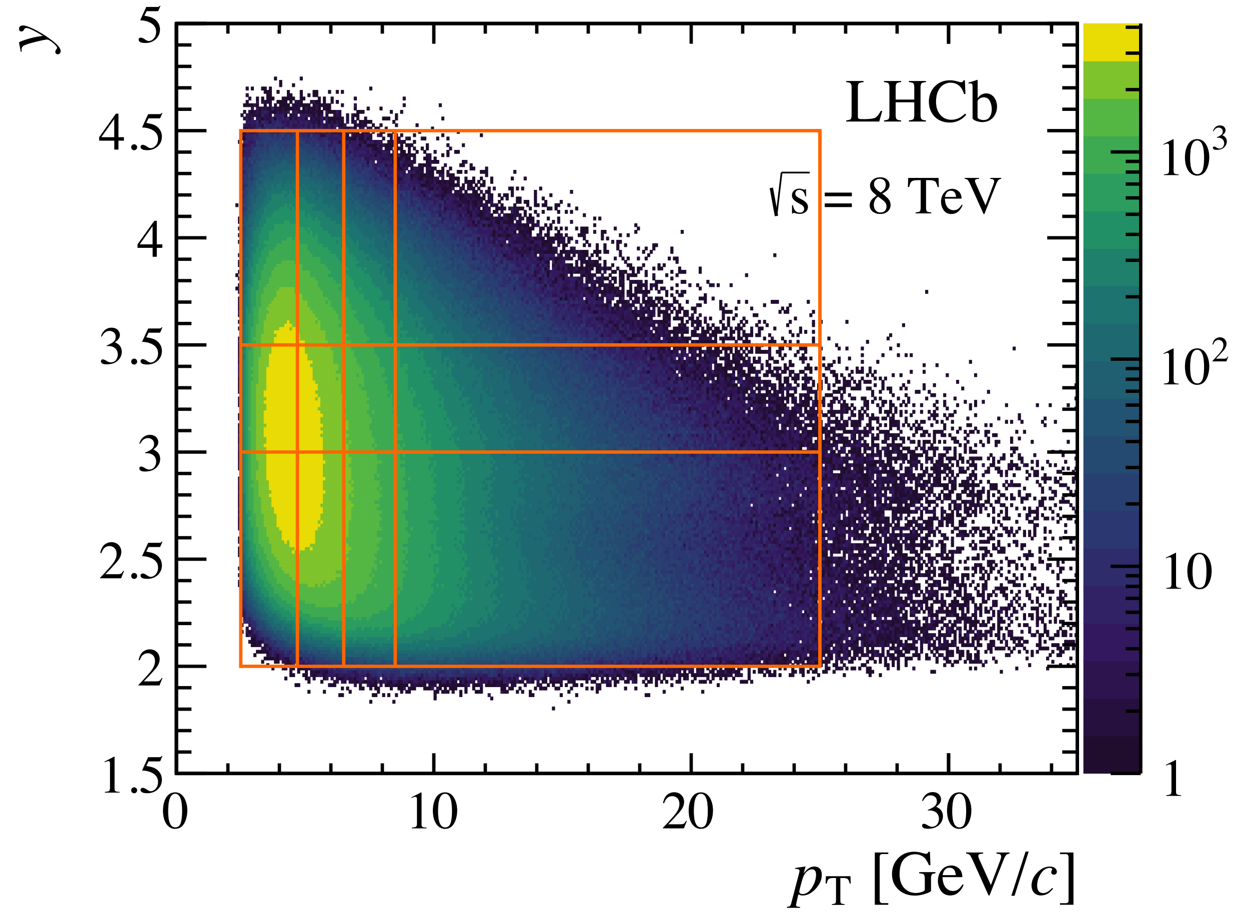
arXiv:1805.09869 (Submitted to JHEP)

Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

Numerical results
(7 and 8 TeV combined)

p_T [GeV/c]	y 2.0 – 3.0	y 3.0 – 3.5	y 3.5 – 4.5
2.5 – 4.7	$-0.63 \pm 0.34 \pm 0.32$	$-0.66 \pm 0.31 \pm 0.13$	$-0.65 \pm 0.33 \pm 0.14$
4.7 – 6.5	$-0.68 \pm 0.25 \pm 0.27$	$-0.06 \pm 0.26 \pm 0.10$	$-0.72 \pm 0.26 \pm 0.13$
6.5 – 8.5	$-0.55 \pm 0.22 \pm 0.06$	$-0.57 \pm 0.26 \pm 0.10$	$-0.48 \pm 0.30 \pm 0.17$
8.5 – 25.0	$-0.40 \pm 0.15 \pm 0.08$	$-0.24 \pm 0.22 \pm 0.10$	$-0.86 \pm 0.33 \pm 0.09$

Binning scheme



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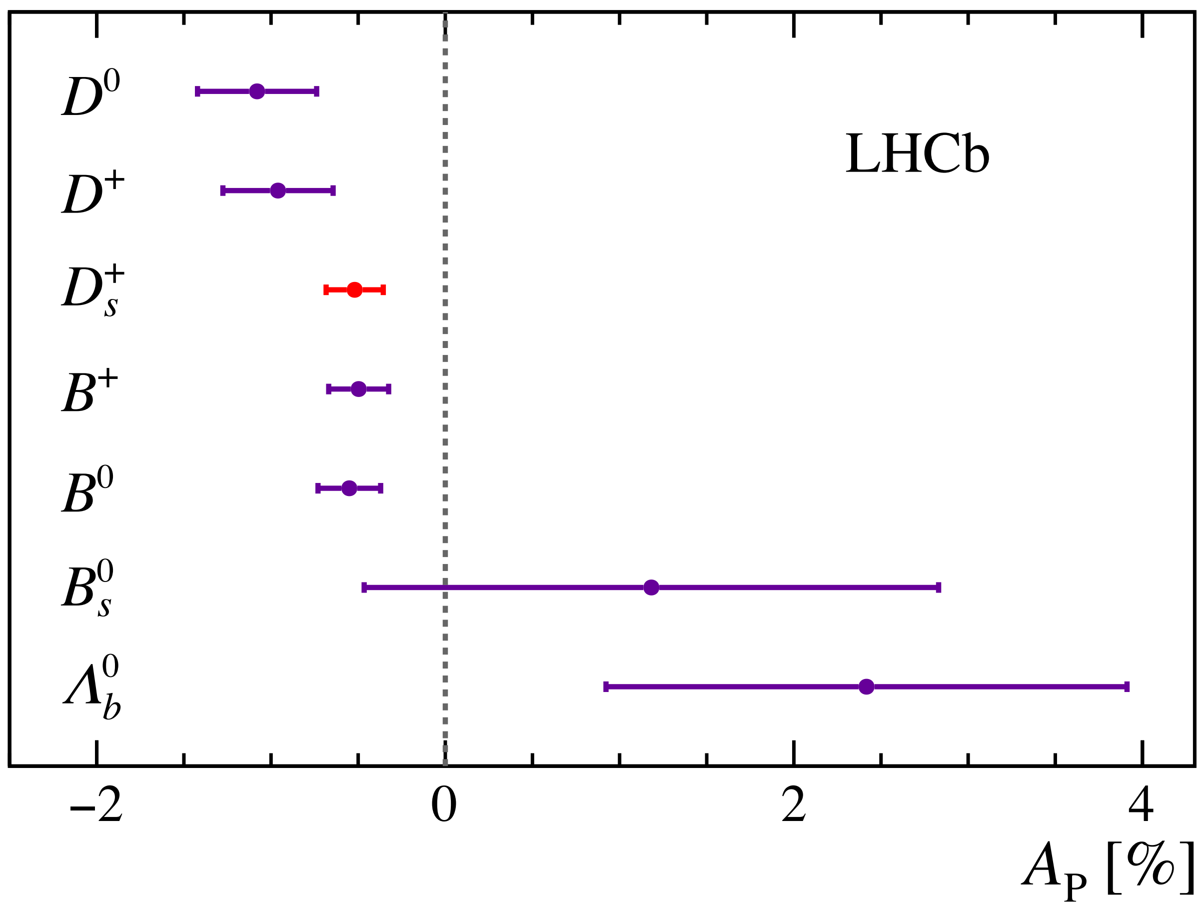
Production asymmetry of D_s^+ at $\sqrt{s}$ = 7 and 8 TeV

Production asymmetry summary



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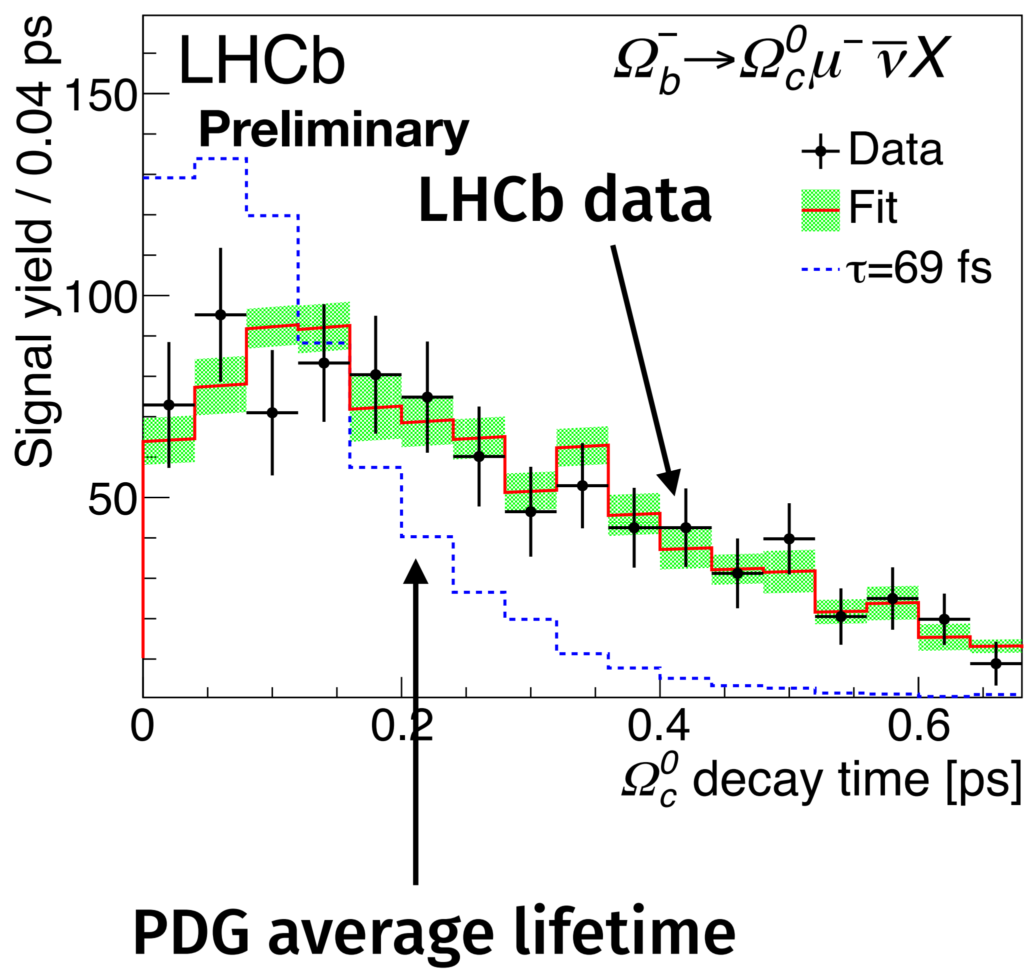
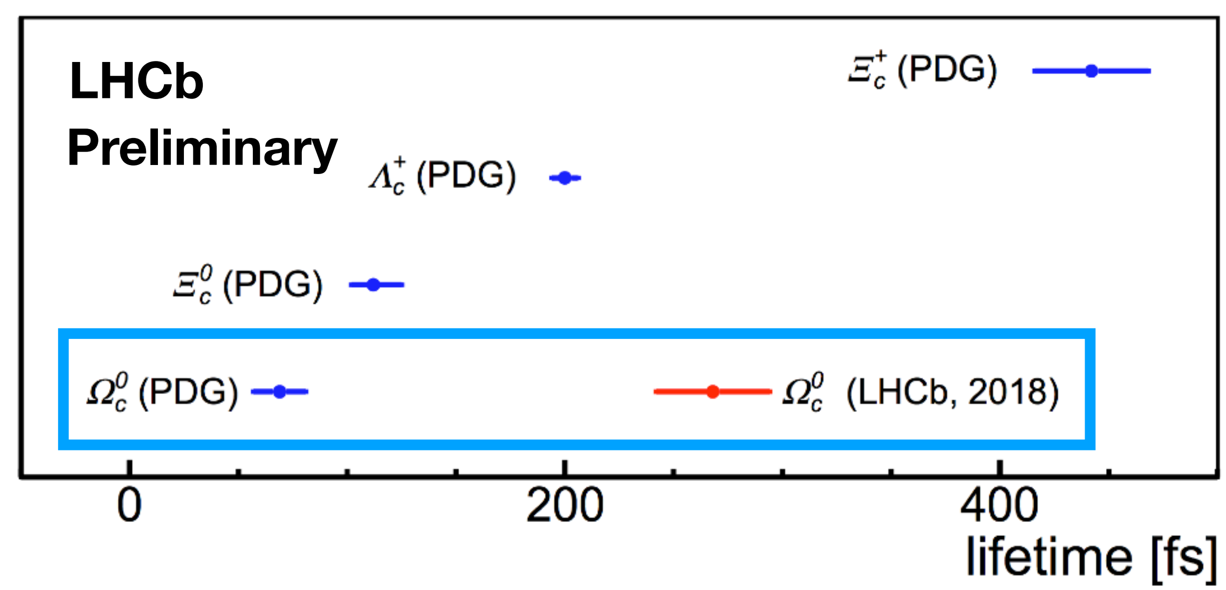
Measurement of the Ω_c^0 lifetime

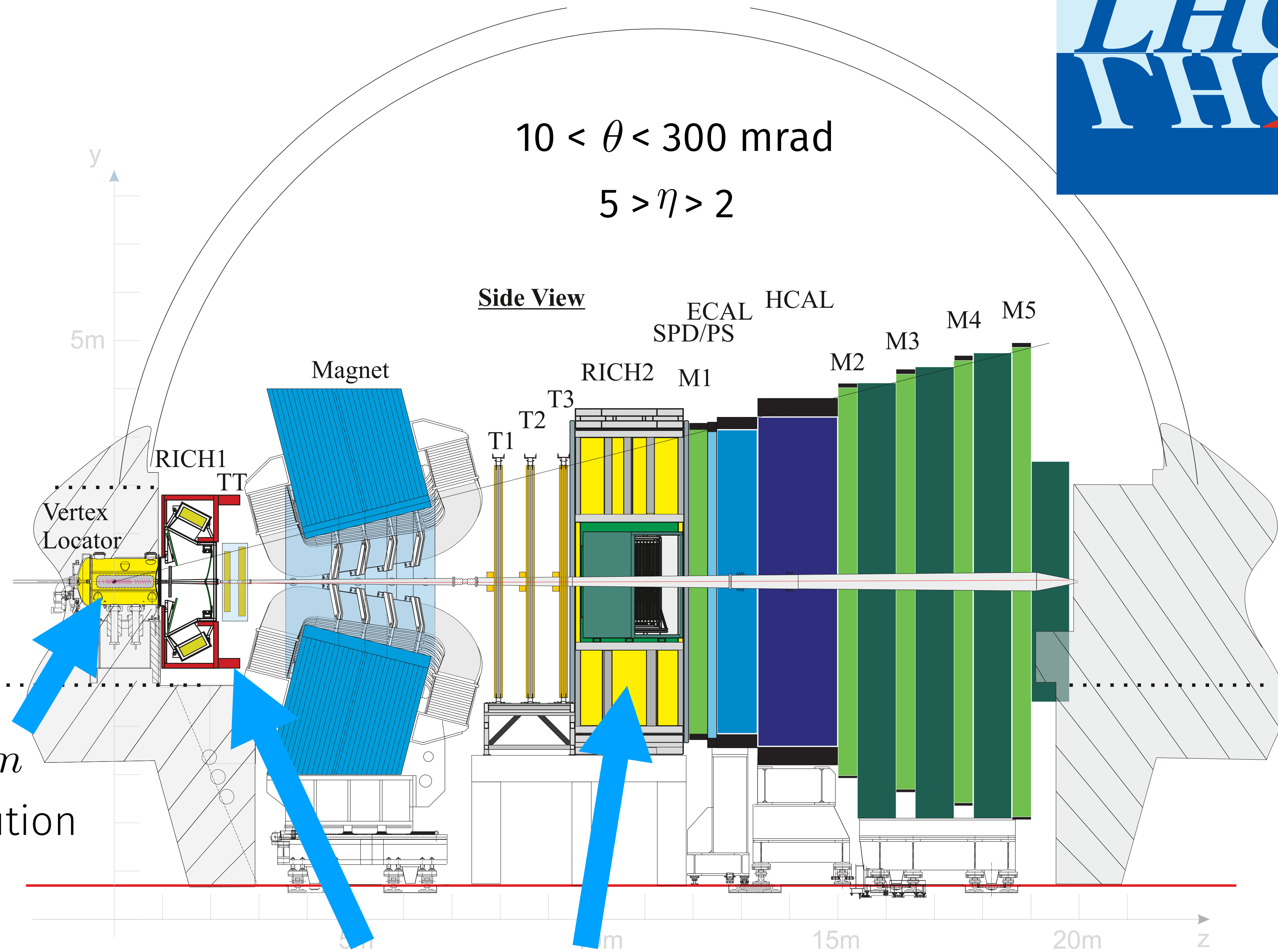




- Cross checked with measurement of D^0 lifetime - consistent with world-average
- Consistent using different background subtraction technique
- Inspection of 13 TeV data gives similar decay time distribution

$10 < \theta < 300$ mrad

$5 > \eta > 2$



$\sim 20\ \mu m$

IP resolution

Separation of charged hadron species via Cherenkov radiation