Baryonic $b \to c$ transitions

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Challenges in semileptonic B decays

20/04/22

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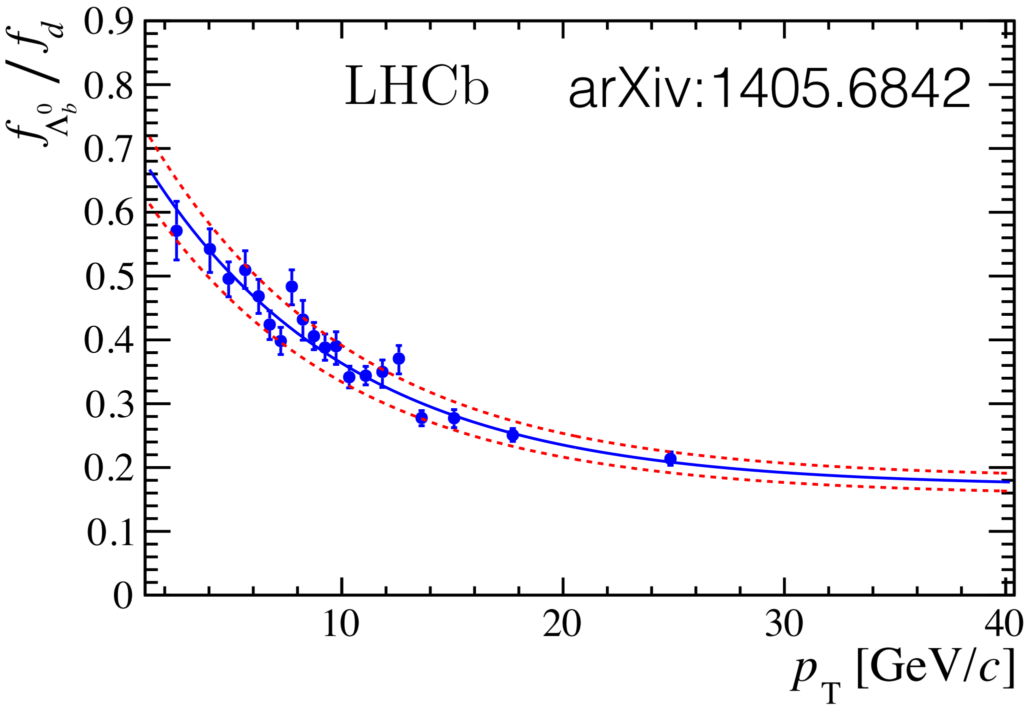
LHCb

What am I talking about

- Traditional $B \to D^{(*)}$ decays well studied at B-factories.

- Unique capability with baryonic decays at LHC

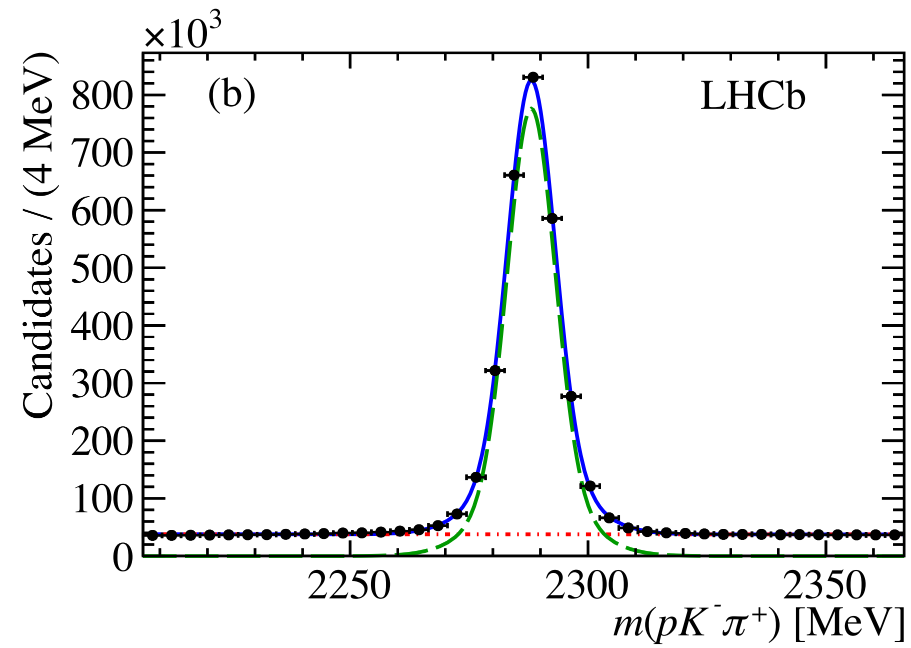


- Large abundance of ground state

$\overline{D}^0 \ell^+ \nu_\ell$	$(2.27 \pm 0.11)\%$
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$	$(6.2^{+1.4}_{-1.3})\%$

PDG 2016

- Baryon number and isospin conservation offer additional protection.



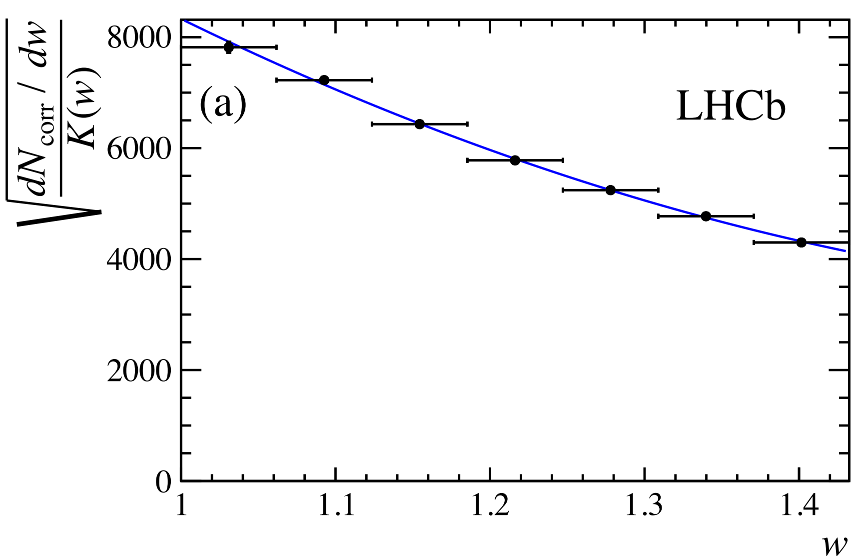
LHCb measurements

- Performed:
  - Determination of $|V_{ub}|/|V_{cb}|$ from $\Lambda_b \to p\mu\nu$ LHCB-PAPER-2015-013
  - $d\Gamma/dq^2$ measurement of $\Lambda_b \to \Lambda_c\mu\nu$ LHCB-PAPER-2017-016
  - Observation of the decay $\Lambda_b \to \Lambda_c\tau\nu$ with $\tau \to \pi\pi\pi(\pi)\nu$. LHCB-PAPER-2021-044
- Planned (non exhaustive):
  - Angular analyses of $\Lambda_b \to \Lambda_c\mu\nu$ (new physics, form factors, V_{cb})
  - Form factor measurements in $\Lambda_b \to \Lambda_c^*\mu\nu$
  - Determination of $R(\Lambda_c)$ via $\tau \to \mu\nu\nu$

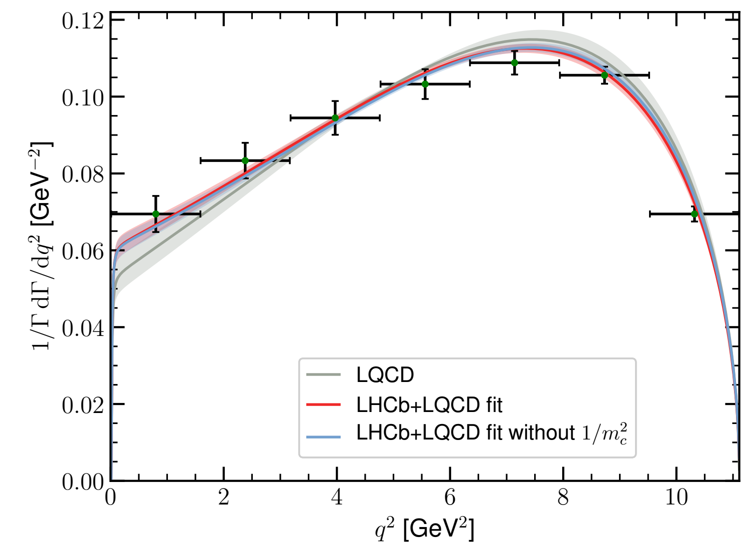
$\Lambda_b^0 \to \Lambda_c^+$ studies

- Fit slope and curvature of the Isgur-Wise function in $\Lambda_b^0 \to \Lambda_c^+$

Phys. Rev. D 96, 112005 (2017)

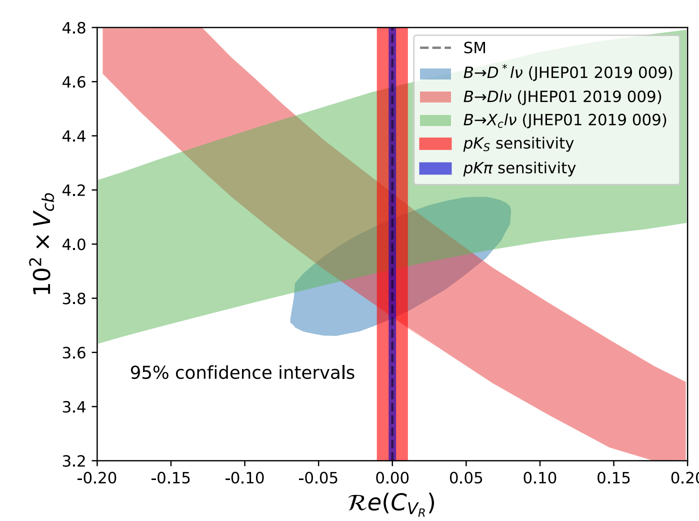


Bernlochner, Ligeti et al, Phys. Rev. D 99, 055008 (2019) , using input from Detmold, Lehner, Meinel, Phys. Rev. D 92, 034503 (2015)



- Released data allowed for full LQCD fit, used to improve precision of R(Λ_c) SM prediction. Important for R(Λ_c) measurements.

Ferrillo et al, JHEP 12 (2019) 148



- Plans: double differential measurement as a function of q^2 and $\cos(\theta_l)$, expect good sensitivity to RH currents.

- Also plans to measure $|V_{cb}|$ using equality of partial widths.

  - Strongly reliant on [1] here, any work such as [2] welcome.

[1] Bigi, Mannel, Uraltsev, JHEP09(2011)012

[2] Bordone, Gambino, arXiv:2203.13107

Observation of $\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$

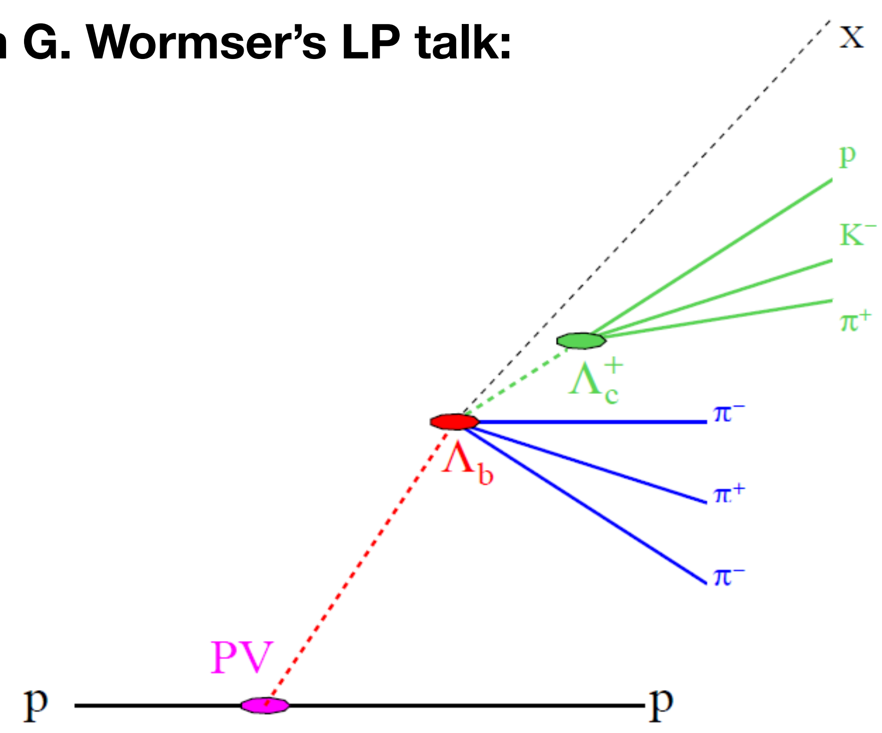
- Test lepton universality with Λ_b decays by measuring $R(\Lambda_c)$:

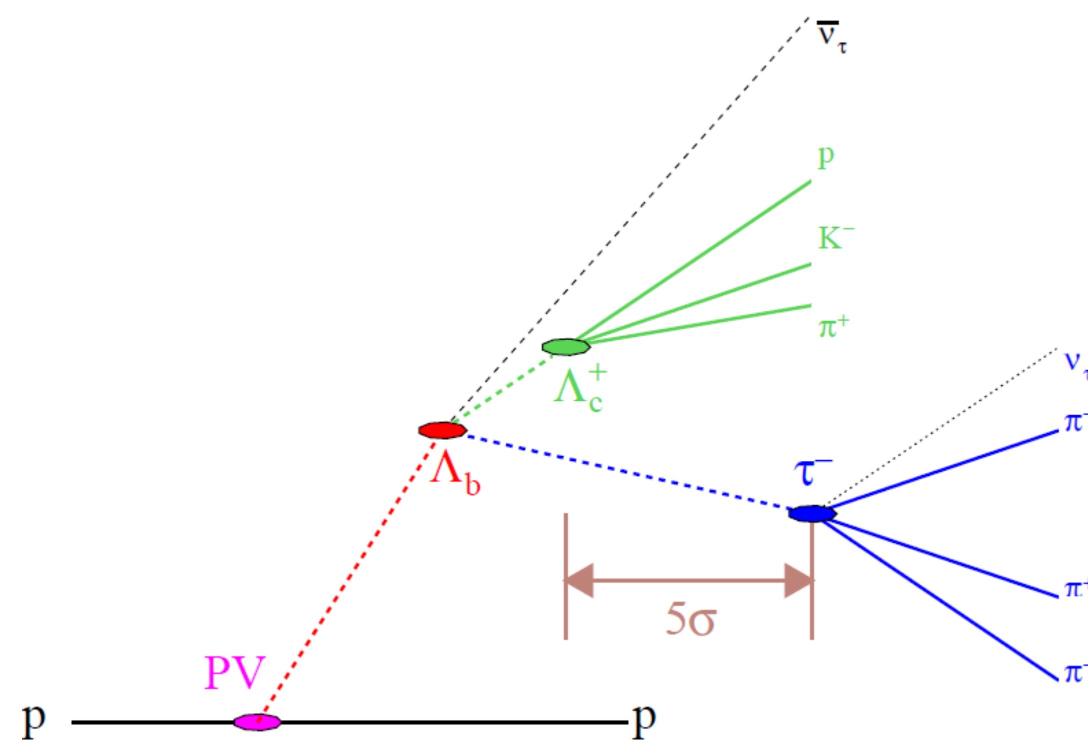
$$R(\Lambda_c) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)}$$

with the semileptonic tau decay τ—>πππ(π)ν.

- Similar strategy to R(D*) measurement.

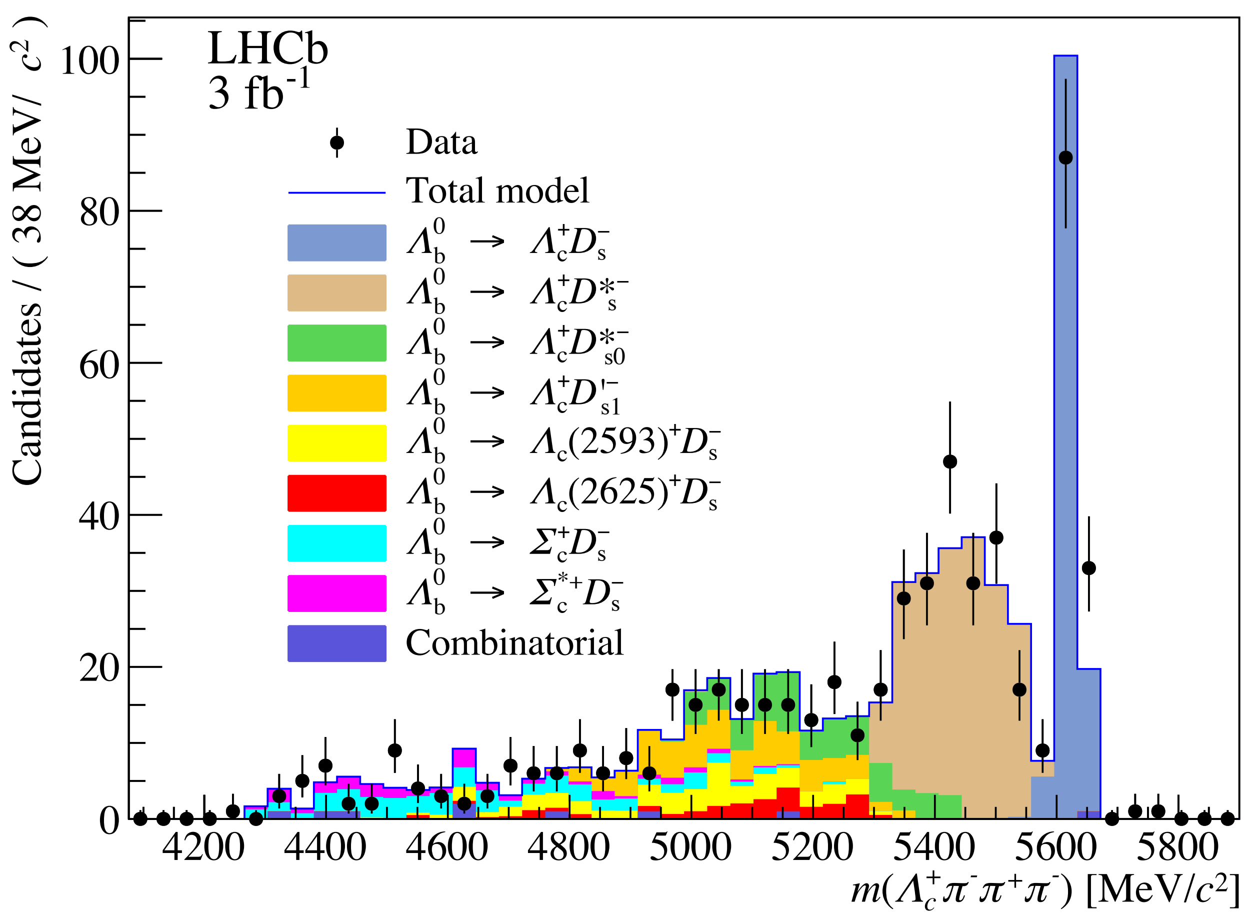
From G. Wormser's LP talk:

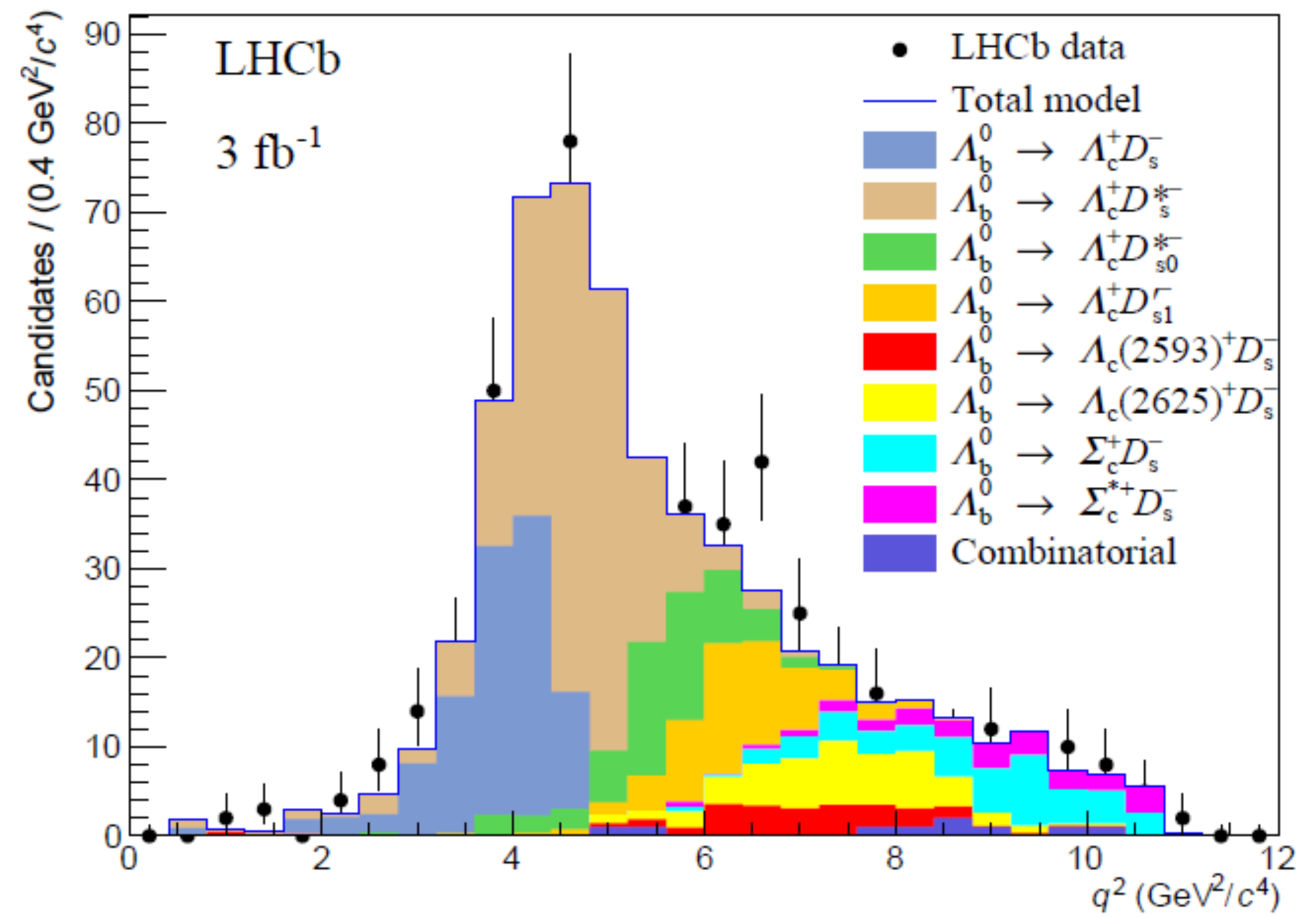




Main background

- Once tight lifetime required, main background from $\Lambda_b \rightarrow X_c X_c$ decays.



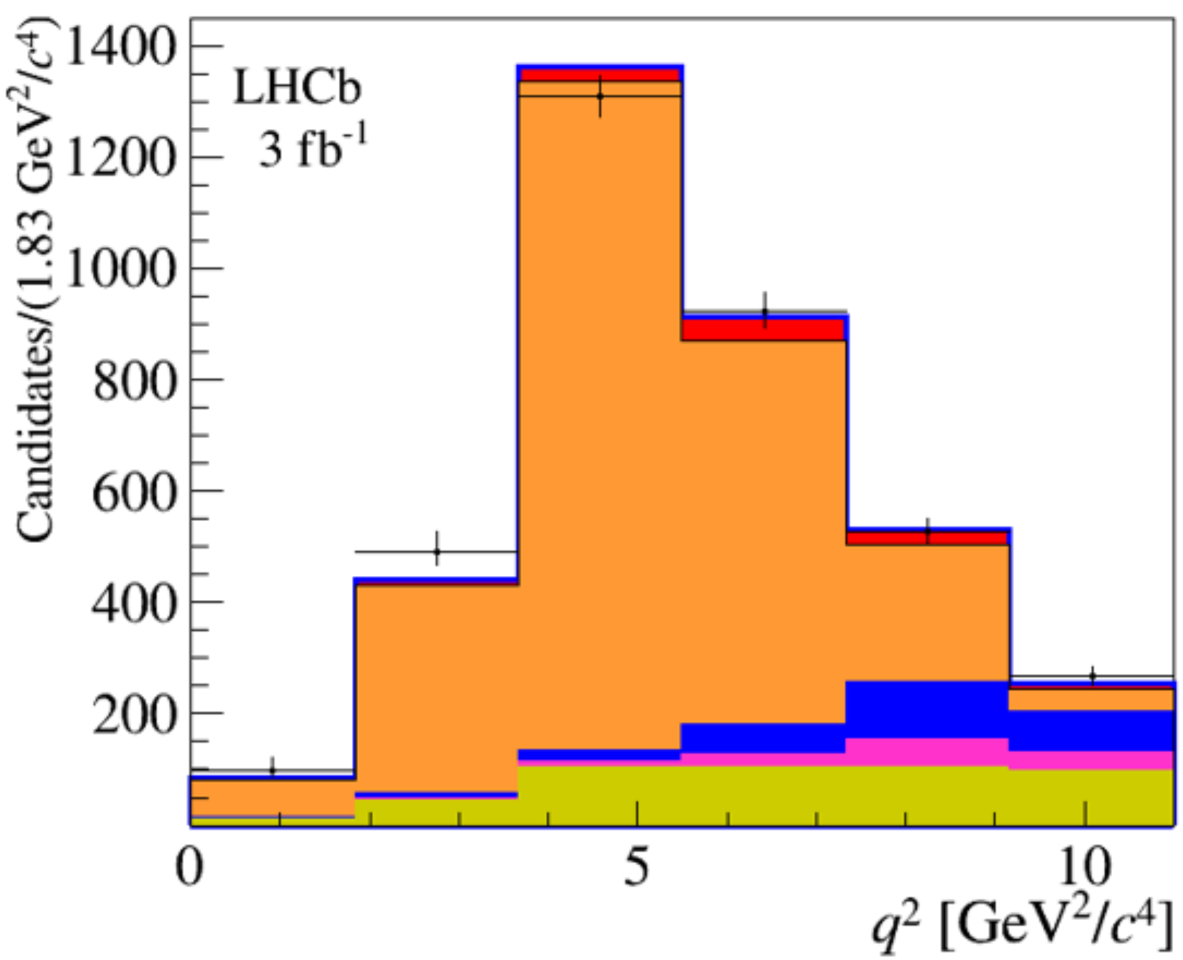


- Controlled by selecting events around a fully reconstructed $D_{(s)}^+$ peak.

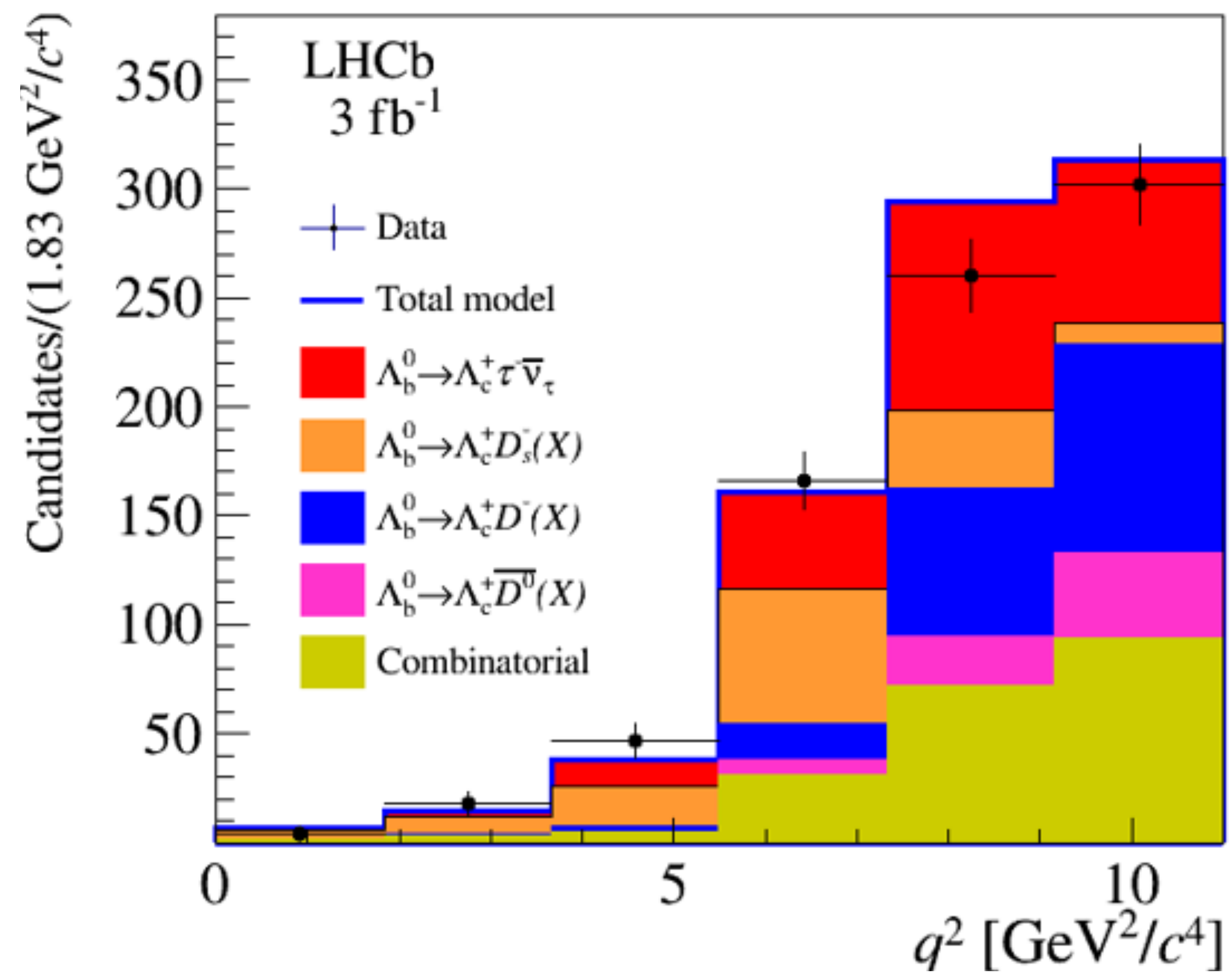
Fit

- 3D fit to decay time, BDT response and q^2.

Low BDT region



High BDT region



- Nice purity seen in high BDT region.

Result

- Normalise measurement to the decay $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$

$$\mathcal{K}(\Lambda_c^+) \equiv \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \overline{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ 3\pi)} = \frac{N_{\rm sig}}{N_{\rm norm}} \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}} \frac{1}{\mathcal{B}(\tau^- \to 3\pi(\pi^0)\nu_\tau)}$$

- Use measurements of $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)$ and $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)$ to convert.

$$R(\Lambda_c^+) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)} \mathcal{K}(\Lambda_c^+)$$

$$\mathcal{R}(\Lambda_c^+) = 0.242 \pm 0.026 \pm 0.040 \pm 0.059$$

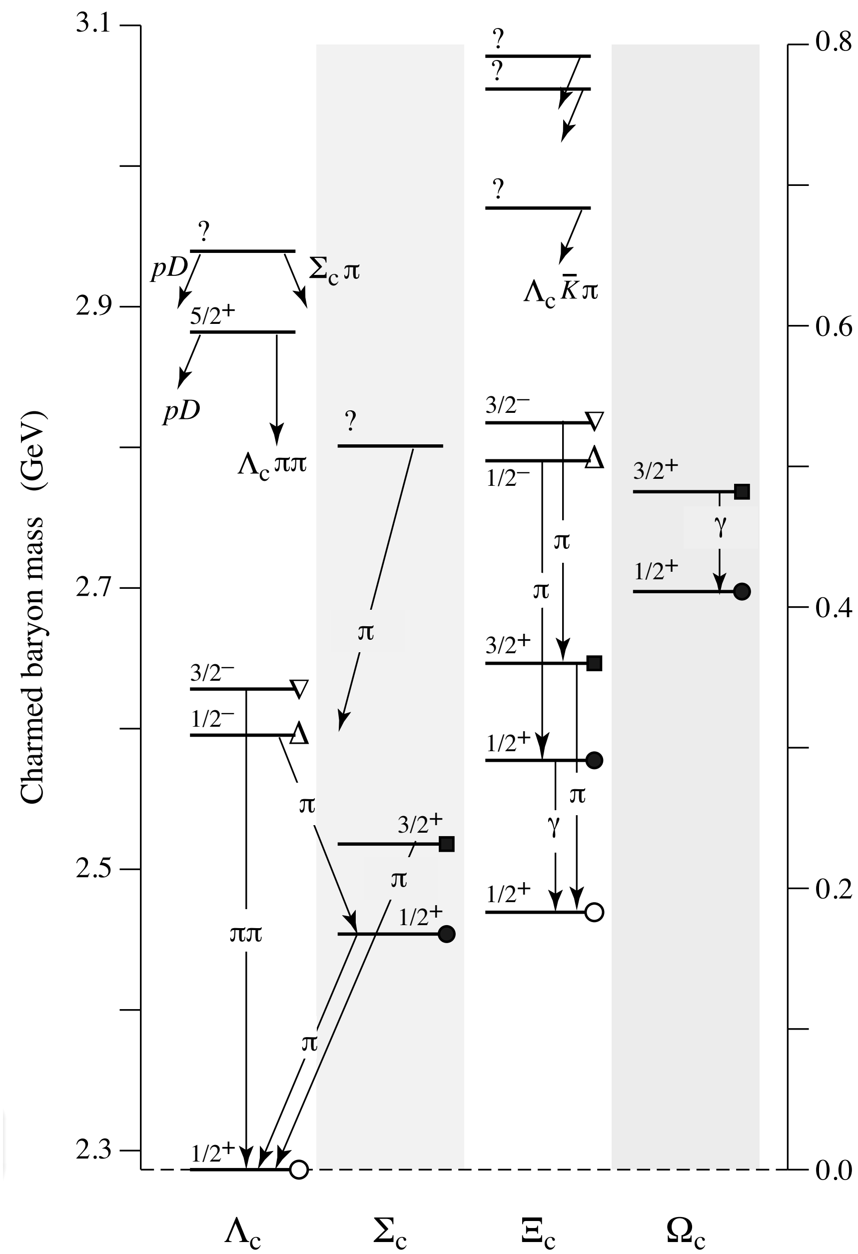
- Consistent with and below the SM prediction [1].

- Only using a fraction of the data, plenty of room to improve with both $\tau \to 3\pi$ and $\tau \to \mu\nu\nu$ decay modes.

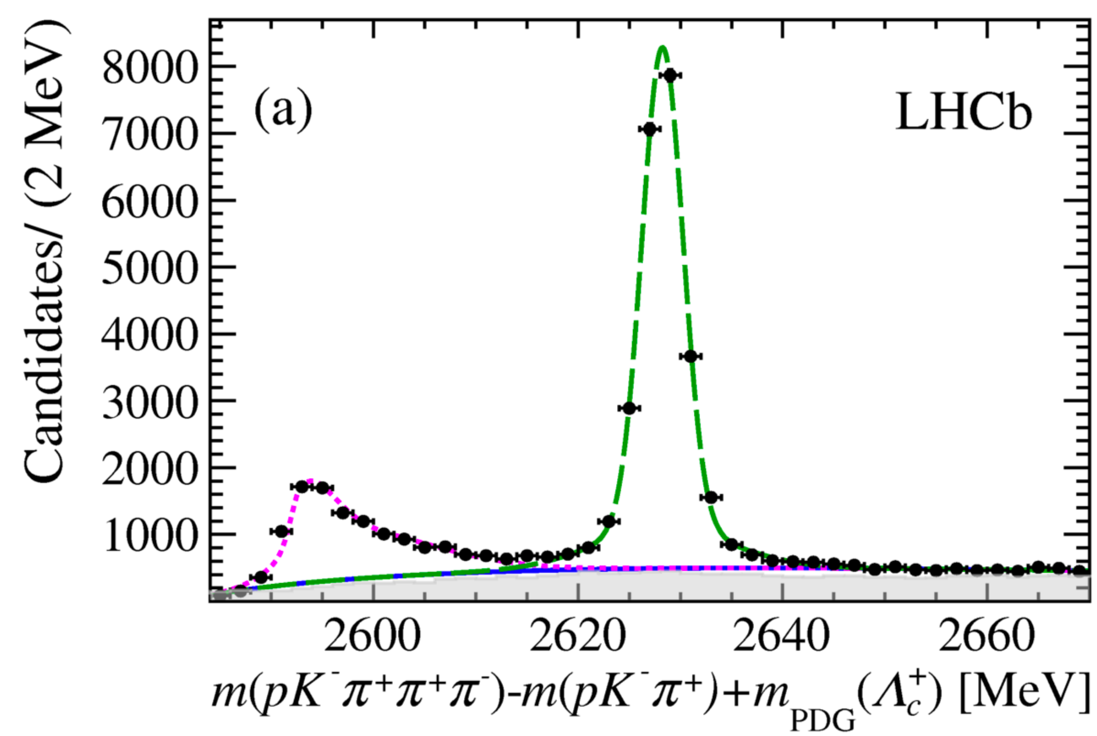
[1] Bernlochner, Ligeti et al, Phys. Rev. D 99, 055008 (2019), using input from Detmold, Lehner, Meinel, Phys. Rev. D 92, 034503 (2015)

The excited state

- In the background studies for the ground state, see many $\Lambda_b^0 \to \Lambda_c^{*+} \mu\nu$ decays



Phys. Rev. D 96, 112005 (2017)



	J^P	Width
$\Lambda_c(2595)^+$	$1/2^-$	2.6 MeV
$\Lambda_c(2625)^+$	$3/2^-$	<1 MeV

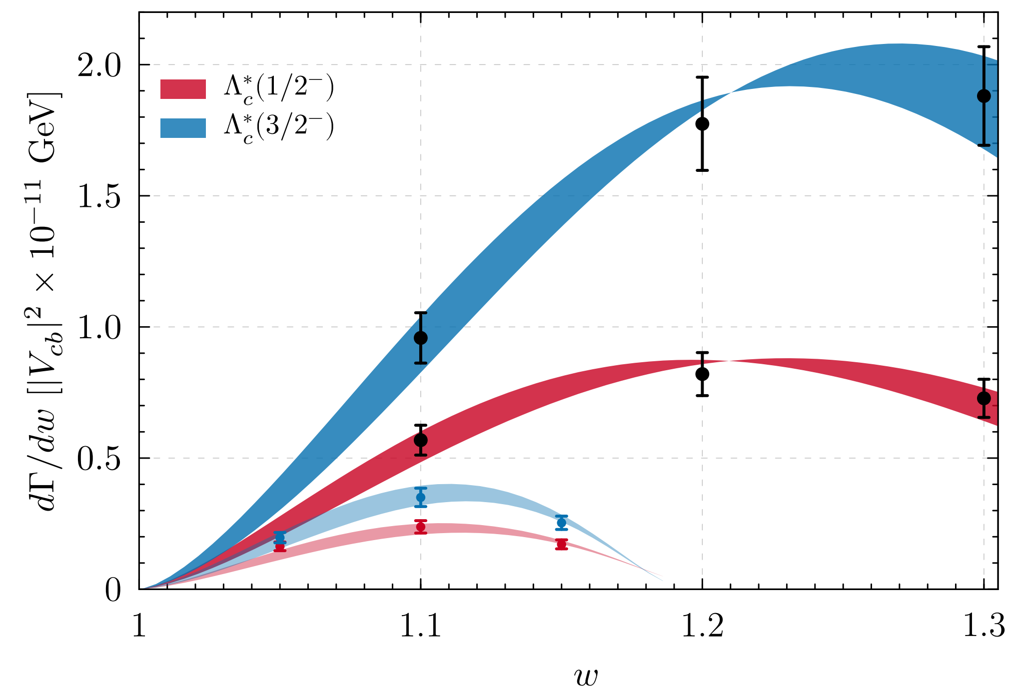
- Plenty of signal, great opportunity to study.
- Branching fractions from CDF: Phys.Rev.D79:032001,2009

$\Lambda_b \longrightarrow \Lambda_c^*$ phenomenology

- Form factors in HQE studied in [1] and expanded in Refs. [2,3].

- In Ref. [2], a specific focus on determining SM prediction for $R(\Lambda_c^{*+})$.

Papucci, Robinson, Phys. Rev. D105 016027



- In heavy quark limit, branching fraction into 3/2 state twice as large as 1/2 state [1].

- CDF measurement appears to show that 1/m corrections not that big (although large uncertainties).

Γ_{43}	$\Lambda_c(2595)^+ \ell^- \overline{\nu}_\ell$	$(7.9^{+4.0}_{-3.5}) \times 10^{-3}$
Γ_{44}	$\Lambda_c(2625)^+ \ell^- \overline{\nu}_\ell$	$(1.3^{+0.6}_{-0.5})\%$

- Endpoint relations will be an interesting input here.

Hiller, Zwicky

[1] Leibovich, Stewart Phys. Rev. D57, 5620 (1998)
[2] Böer, Bordone et al, JHEP 06, 155 (2018)
[3] Papucci, Robinson, Phys. Rev. D105 016027

The Λ_c^* branching fraction

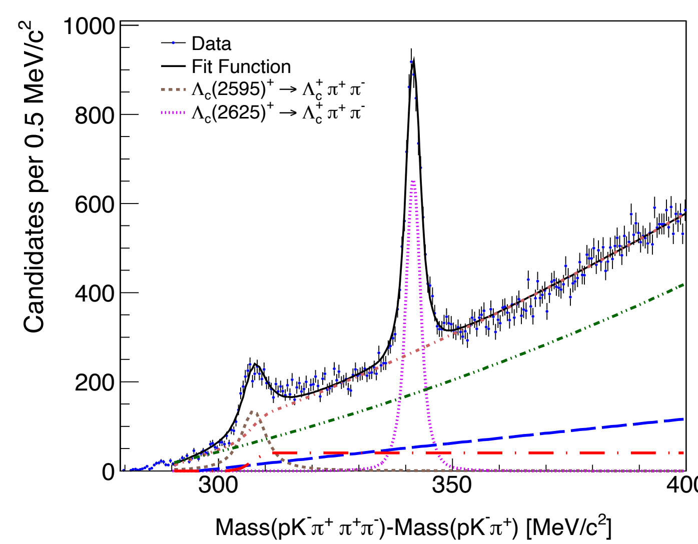
Credit: M. Rotondo

- Λ_c^* decays reconstructed through the $\Lambda_c\pi^+\pi^-$ decay mode.
  - Based on PDG, would use isospin rules to predict:

$$\mathcal{B}(\Lambda_c(2595)^+ \to \Lambda_c^+\pi^+\pi^-) = \mathcal{B}(\Lambda_c(2625)^+ \to \Lambda_c^+\pi^+\pi^-) = 2/3$$

- However, expect kinematic suppression for 1/2 state as its almost on threshold.

CDF, Phys.Rev.D84:012003,2011



$$\mathcal{B}(\Lambda_c(2595)^+ \to \Lambda_c^+\pi^+\pi^-) \sim 18.5\%$$
$$\mathcal{B}(\Lambda_c(2625)^+ \to \Lambda_c^+\pi^+\pi^-) \sim 55\%$$

Numbers extracvted from https://arxiv.org/abs/1907.05747

- This reverses the BF hierarchy of the two Λ_b decays, agreeing with LQCD.

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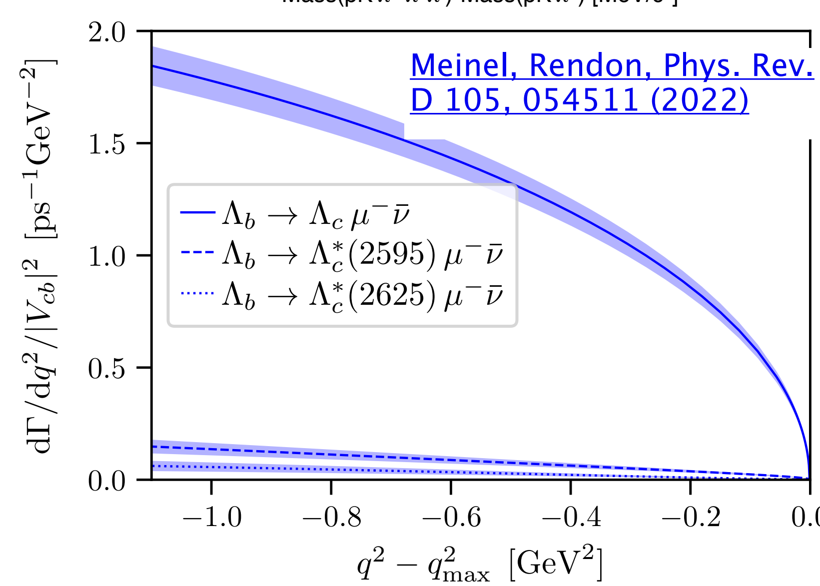
Γ_{44}	$\Lambda_c(2625)^+\ell^-\overline{\nu}_\ell$	$(1.3^{+0.6}_{-0.5})\%$

x4

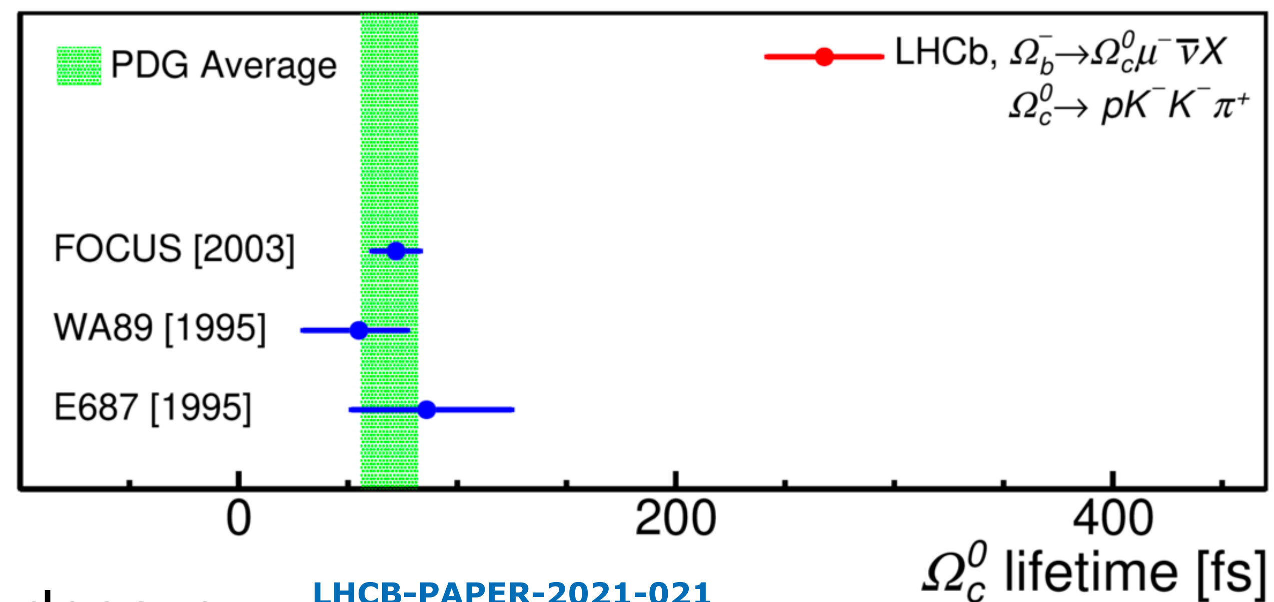


Slight tangent to finish

- Not strictly a semileptonic measurement, but quite a fun one:

LHCB-PAPER-2018-028

- LHCb measurement much more precise and disagrees with WA from three different experiments.



LHCB-PAPER-2021-021

- LHCb result recently confirmed with prompt decays

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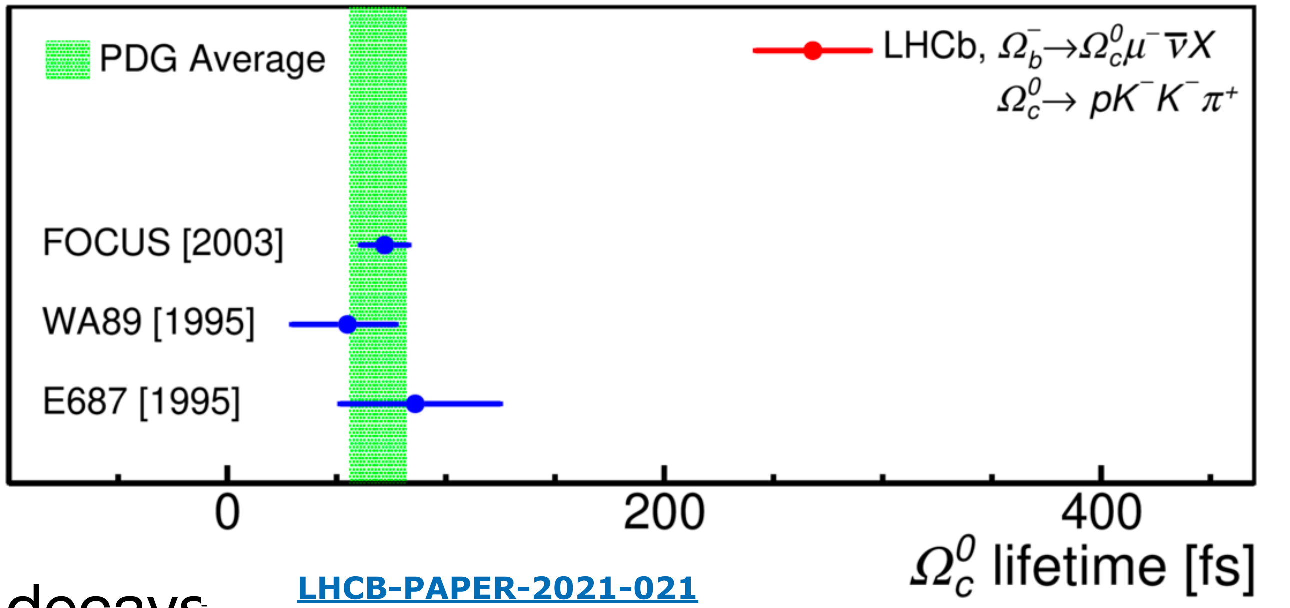

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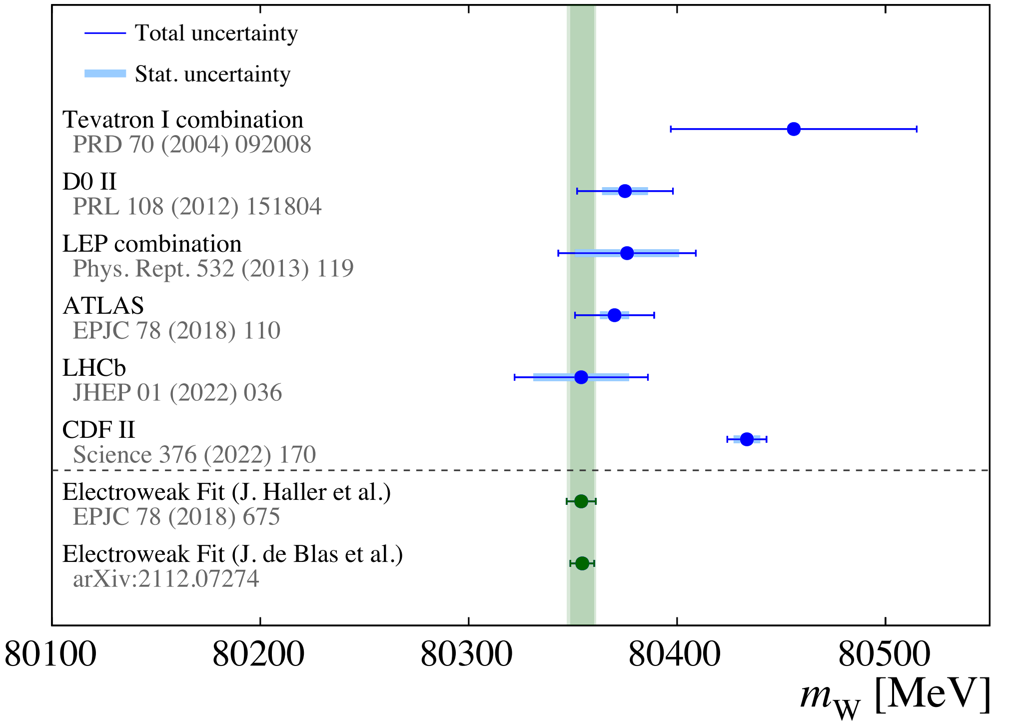
LHCB-PAPER-2021-021

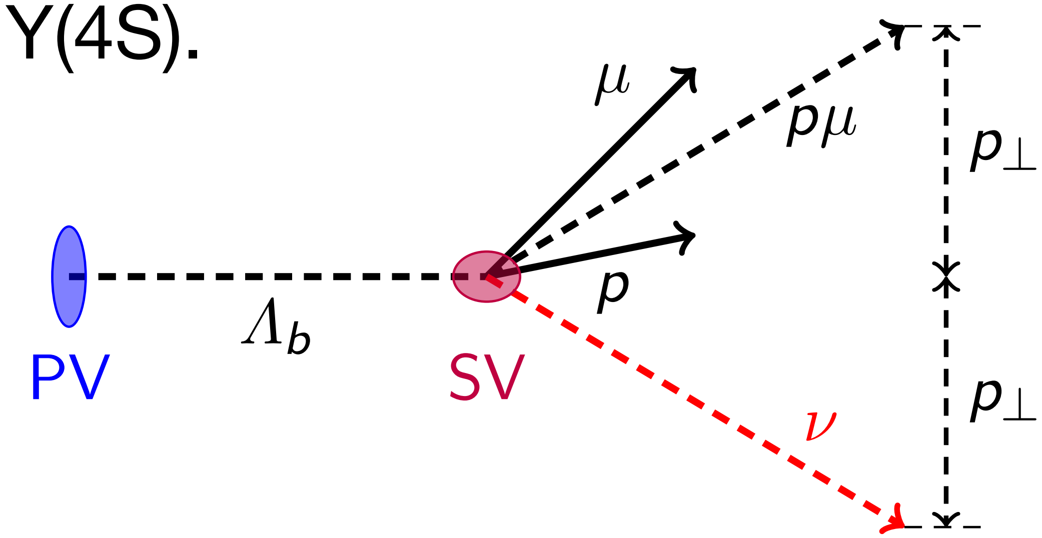
- Look familiar?



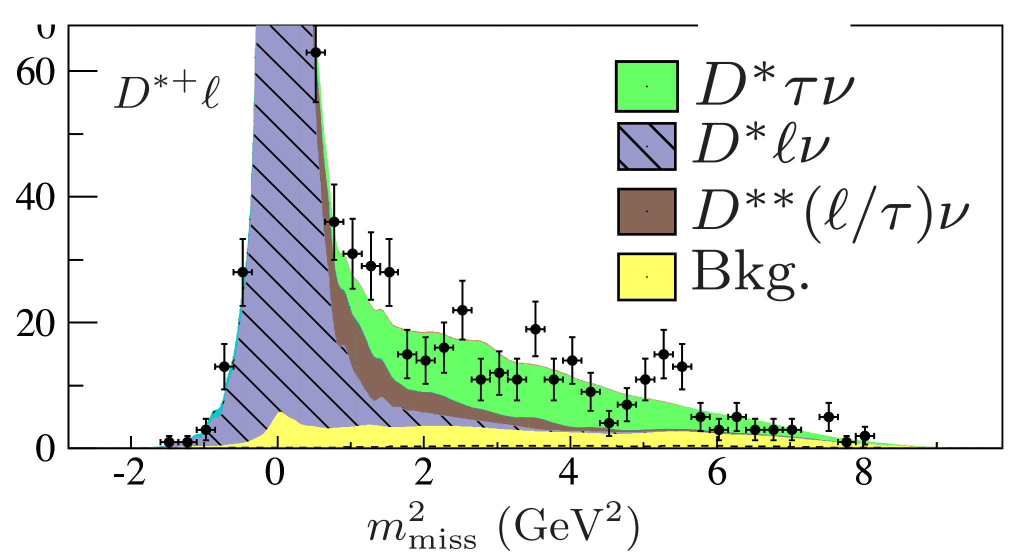
No summary

SL decays at a hadron collider

- Its more difficult to do SL decays at a hadron collider.
- Less kinematic constraints than from Y(4S).
- General rule: '**B-factories good at the X-axis, LHCb good at the Y-axis**'.

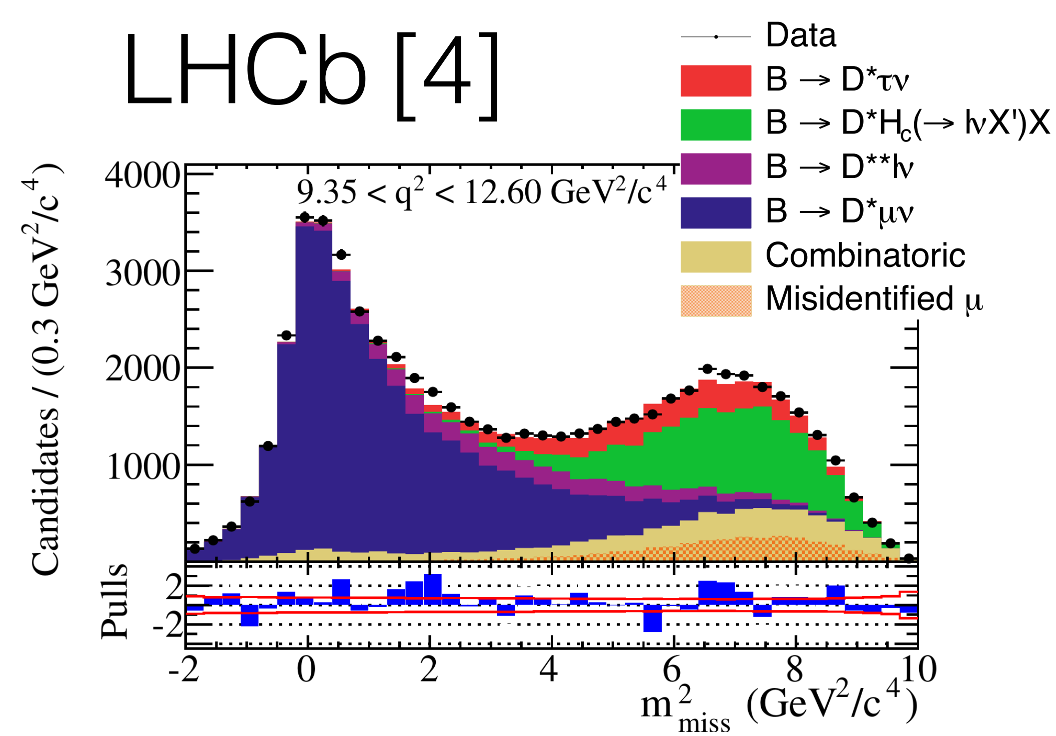


BaBar [3]



vs

LHCb [4]



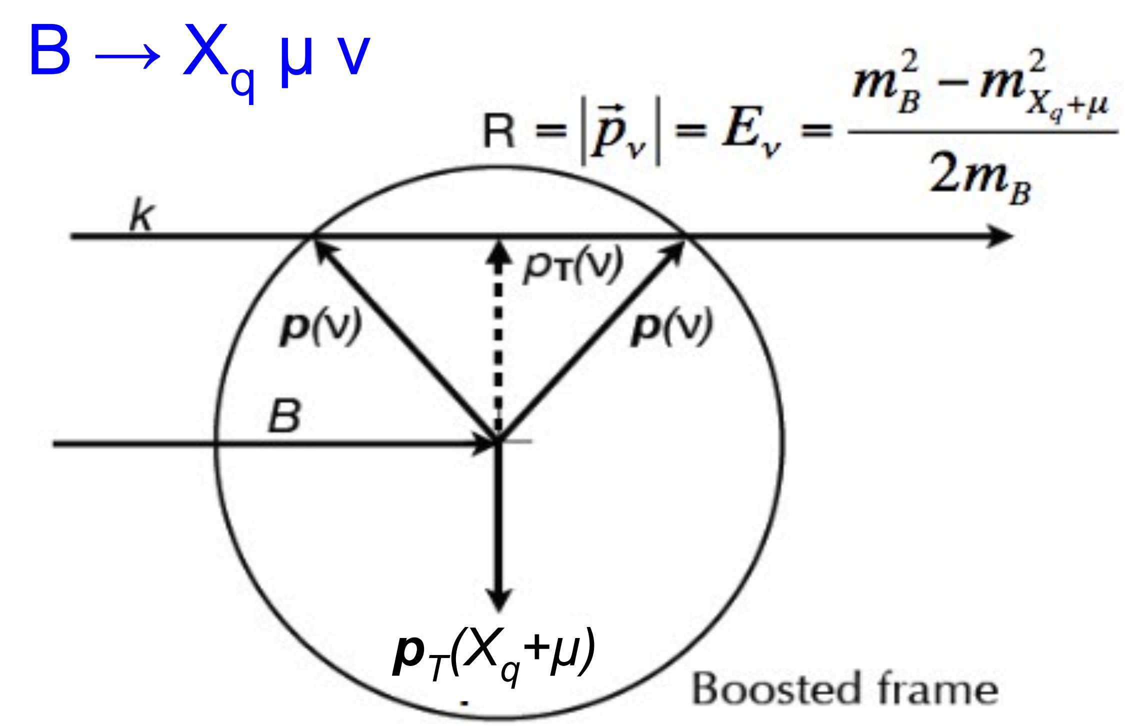
[3] Phys. Rev. D 88, 072012 (2013)

[4] Phys.Rev.Lett.115, 111803 (2015)

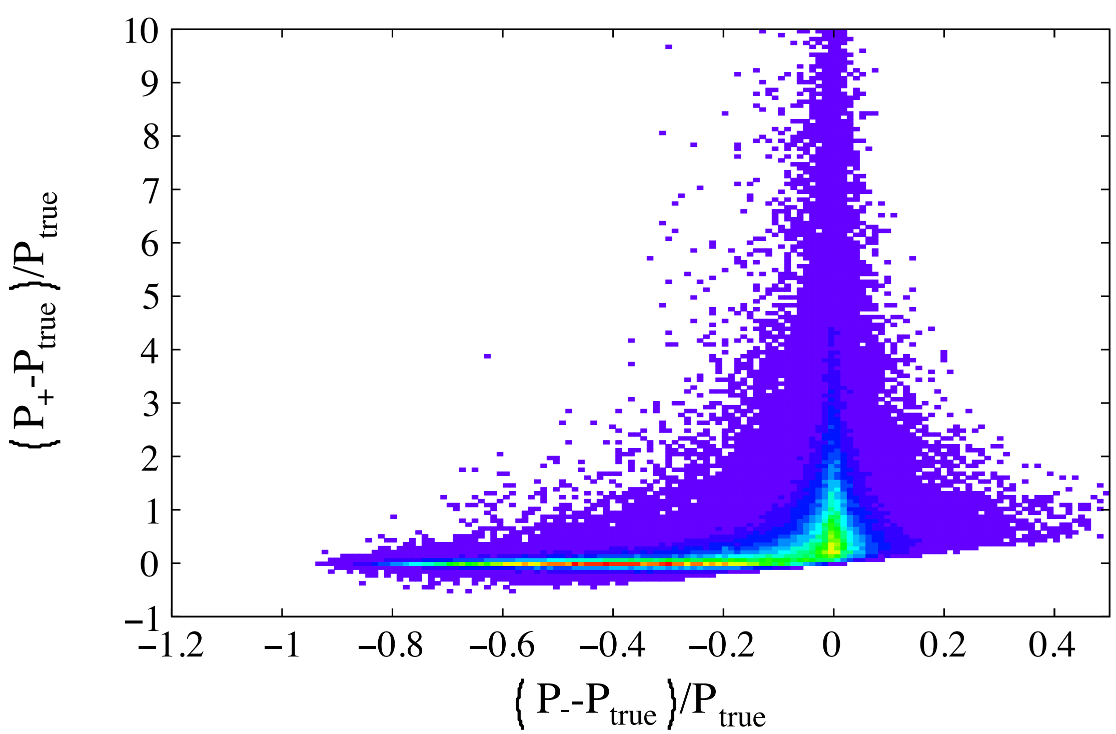
Neutrino reconstruction

- Significant flight of the b-hadron allows to balance momentum transverse to the flight direction [5].

- Parent mass gives another (quadratic) constraint, can solve with two-fold ambiguity.



From Marcello's talk at CKM



- For $b \to c$ decays it seems that the solution corresponding to the lowest neutrino momentum is more often correct than not.

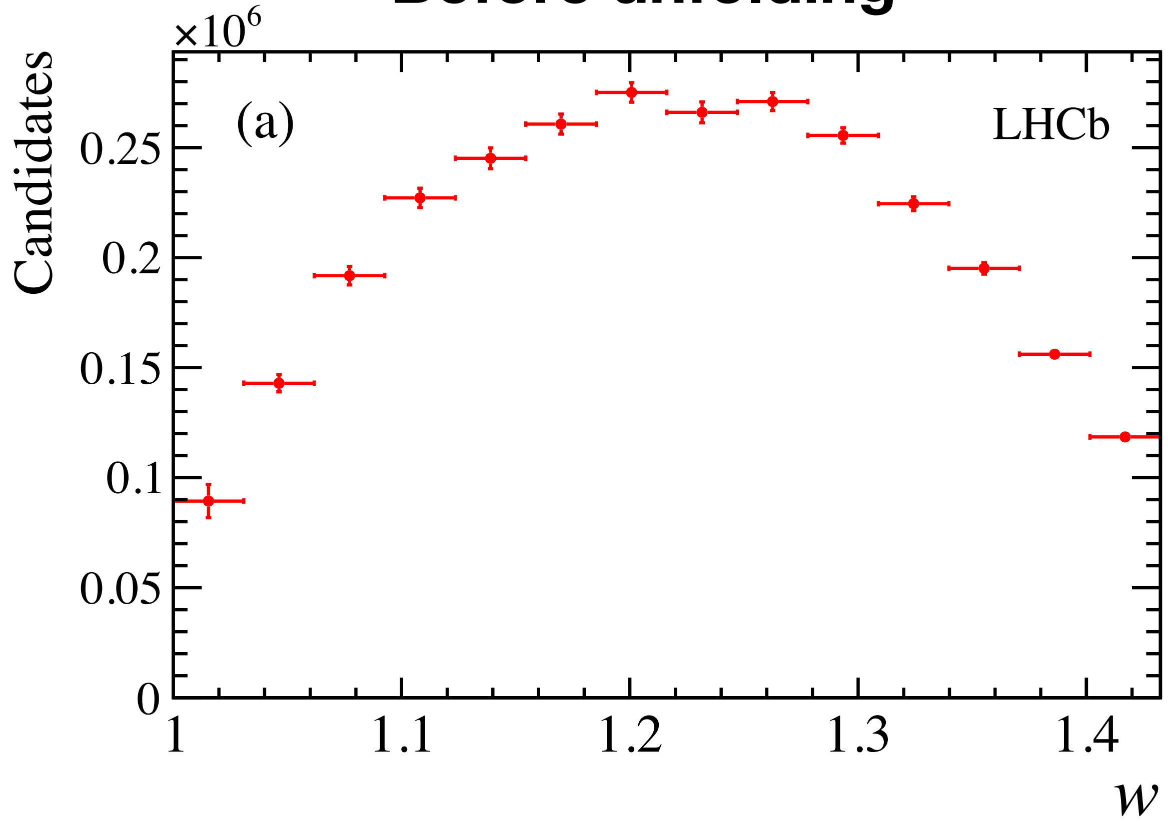
[5] S. Dambach, U. Langenegger, A. Starodumov, Nucl.Instrum.Meth. A569 (2006) 824-828

Phys. Rev. D 96, 112005 (2017)

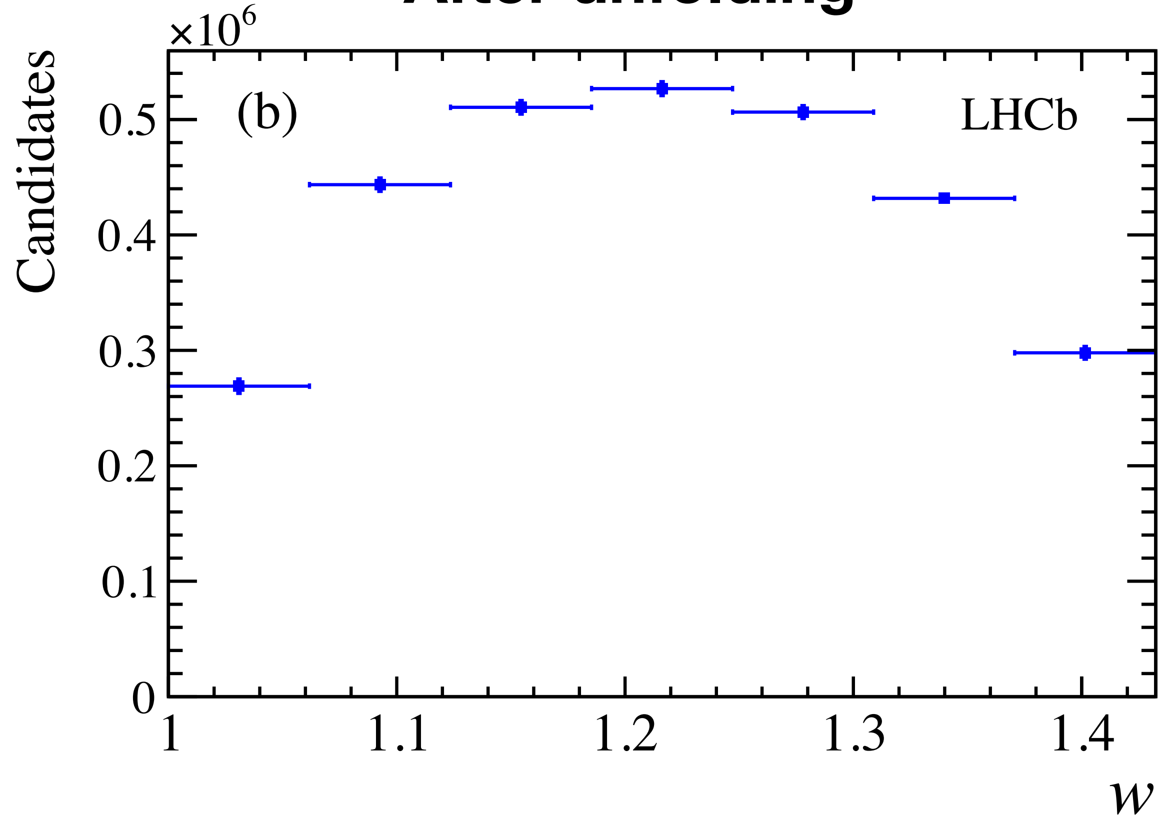
Unfolding

- Distribution unfolded using the SVD technique [6] with regularisation = 4.

Before unfolding



After unfolding



- Different regularisation parameters checked for systematic.
- Efficiency generally low at the edges of the phase-space, due to low momentum muon (trigger) or hadron (reconstruction/selection).

[6] Hoecker, Kartelishvili, Nucl.Instrum.Meth.A372:469-481,1996