Baryonic $b \to c$ transitions

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Challenges in semileptonic B decays

09/04/18

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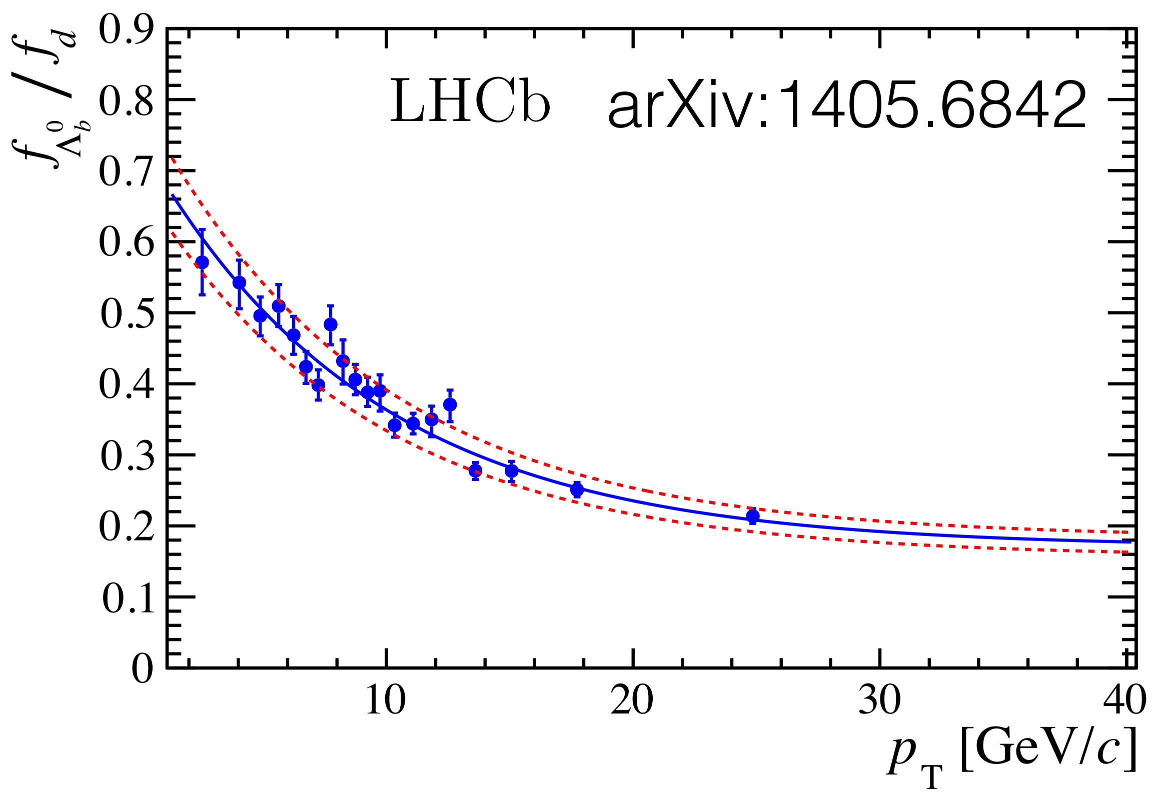
LHCb

What am I talking about

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

- LHCb has unique capability with baryonic decays.



- Unique spin structure

- 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

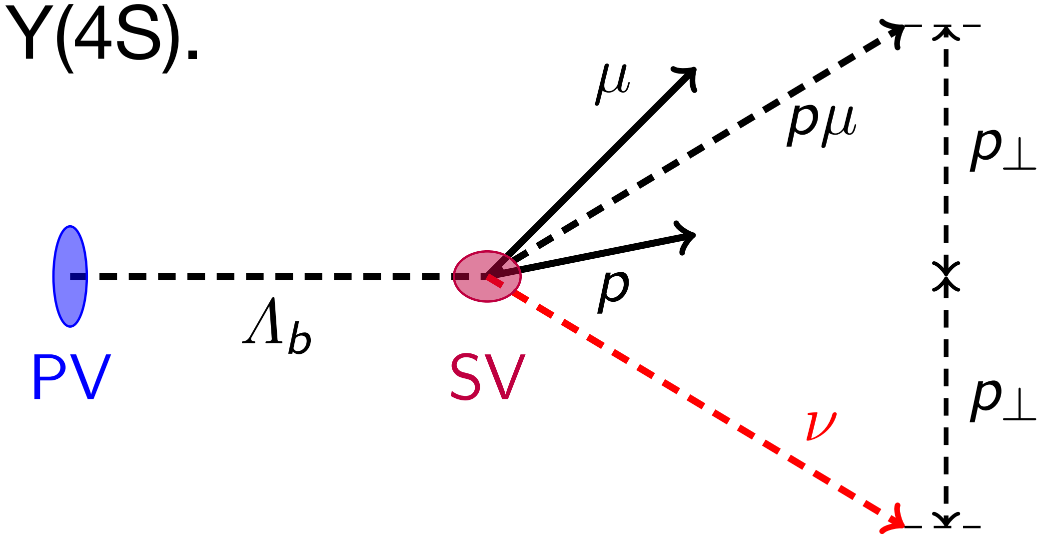
- Baryon number and isospin conservation offer additional protection.

- Today I will talk about LHCb analysis on ground state[1], and pheno analysis on Λ_c^* state [2].

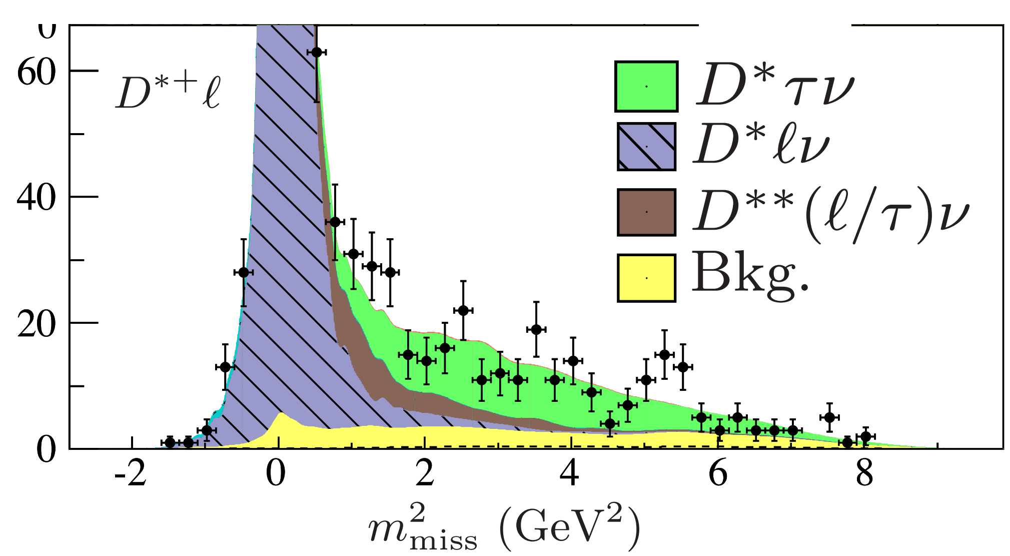
[1] Phys. Rev. D 96, 112005 (2017)
[2] Böer, Bordone, Graverini, Owen, Rotondo, van Dyk

SL decays at a hadron collider

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

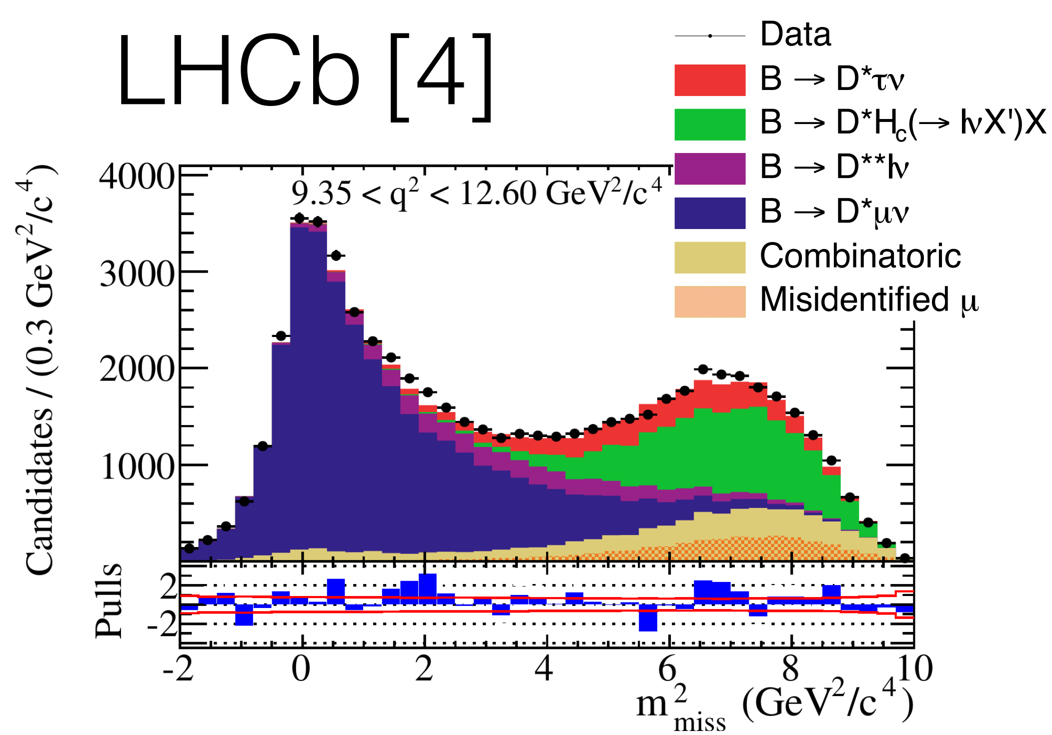


BaBar [3]



vs

LHCb [4]



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

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

Phys. Rev. D 96, 112005 (2017)

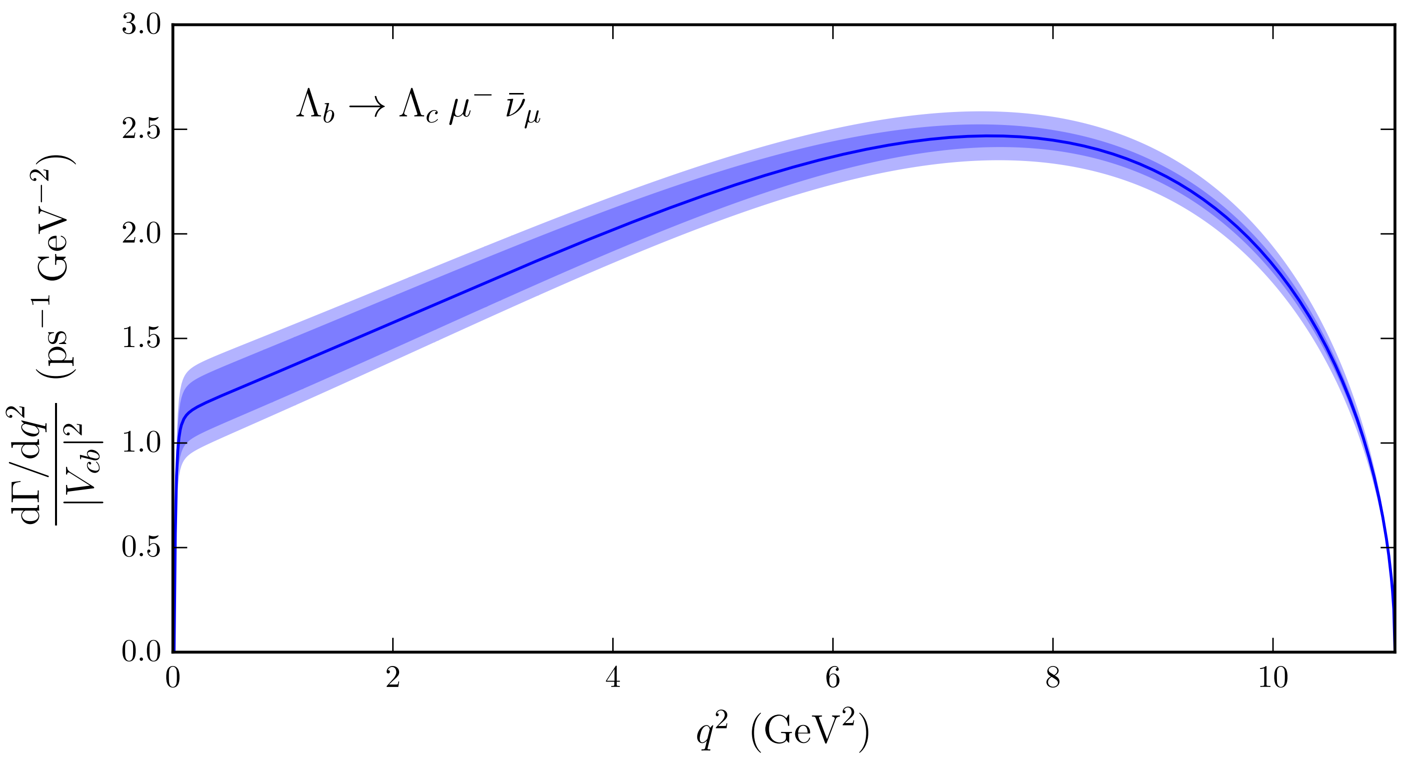
$\Lambda_b^0 \to \Lambda_c^+$ form factors

- First step: measurement $\Lambda_b^0 \to \Lambda_c^+$ differential slope.
- Check the precise lattice results.
- Showcase the potential for LHCb form factor measurements.

- In the heavy quark limit, form factors reduced to a single Isgur-Wise function. [Falk, Neuburt, '92]
- Perform a Taylor expansion and fit first two terms:

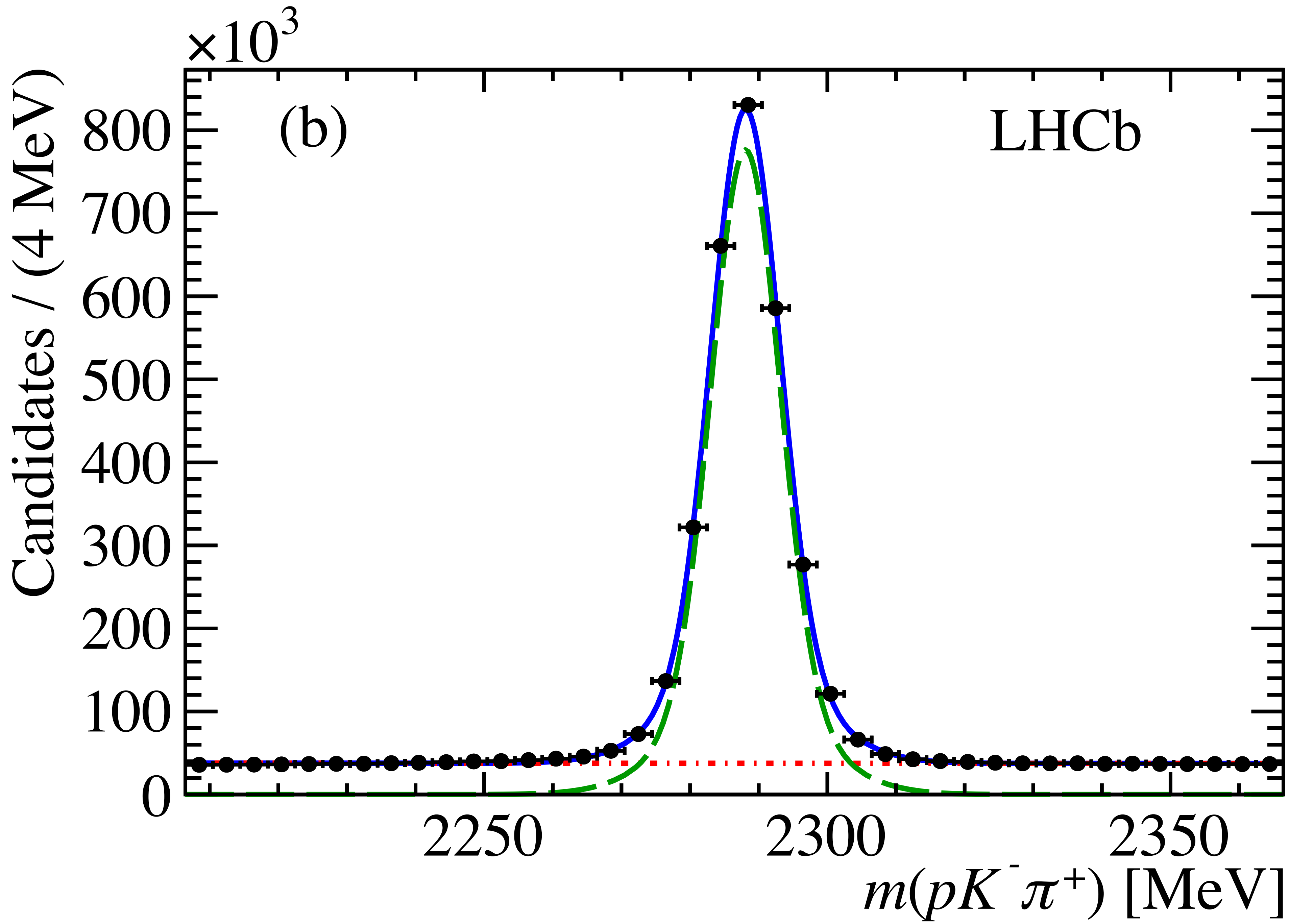
$$\xi_B(w) = 1 - \underbrace{\rho^2}_{\text{Slope}}(w-1) + \frac{1}{2}\underbrace{\sigma^2}_{\text{Curvature}}(w-1)^2 + \ldots,$$

Detmold, Lehner, Meinel, Phys. Rev. D 92, 034503 (2015)



Lots of signal

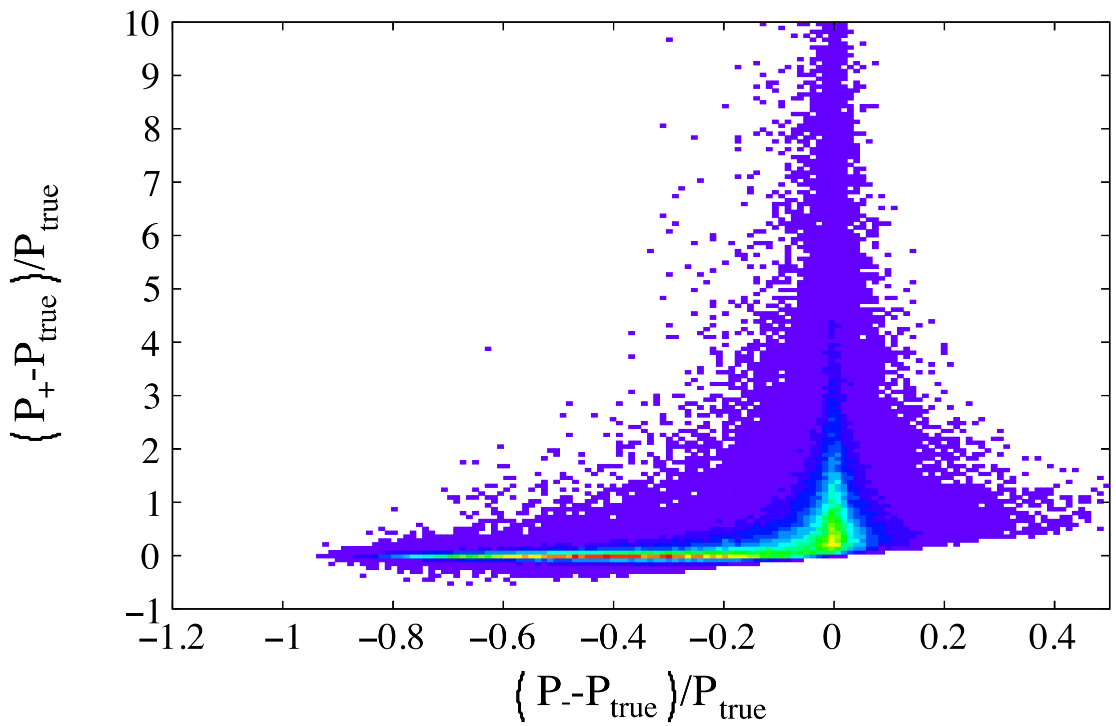
Phys. Rev. D 96, 112005 (2017)

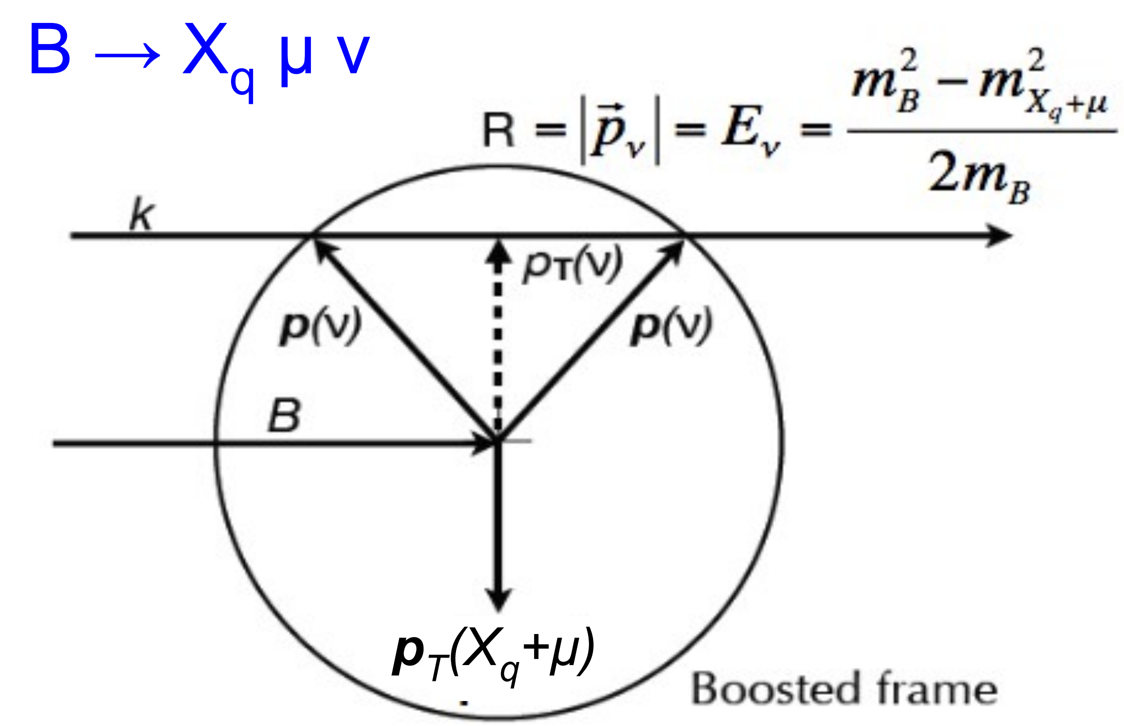


Neutrino reconstruction

- 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.

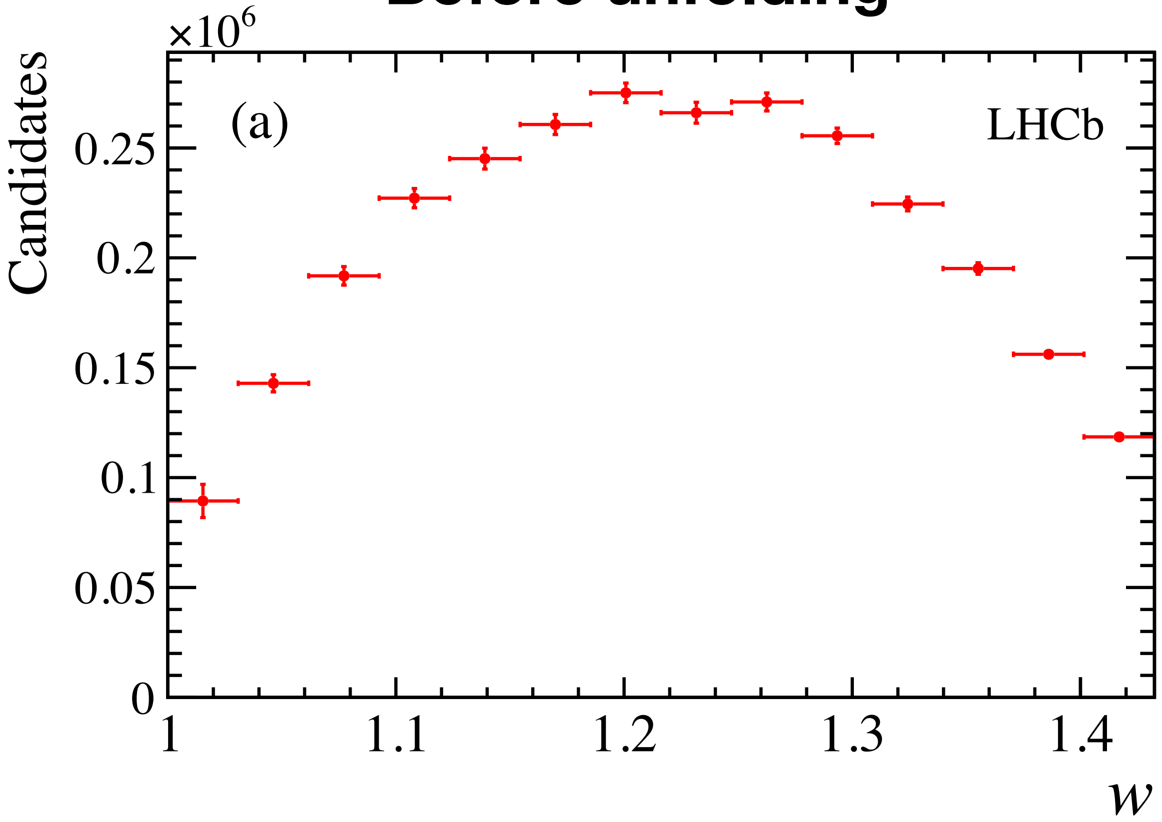
[5] S. Dambach, U. Langenegger, A. Starodumov, Nucl.Instrum.Meth. A569 (2006) 824-828

Phys. Rev. D 96, 112005 (2017)

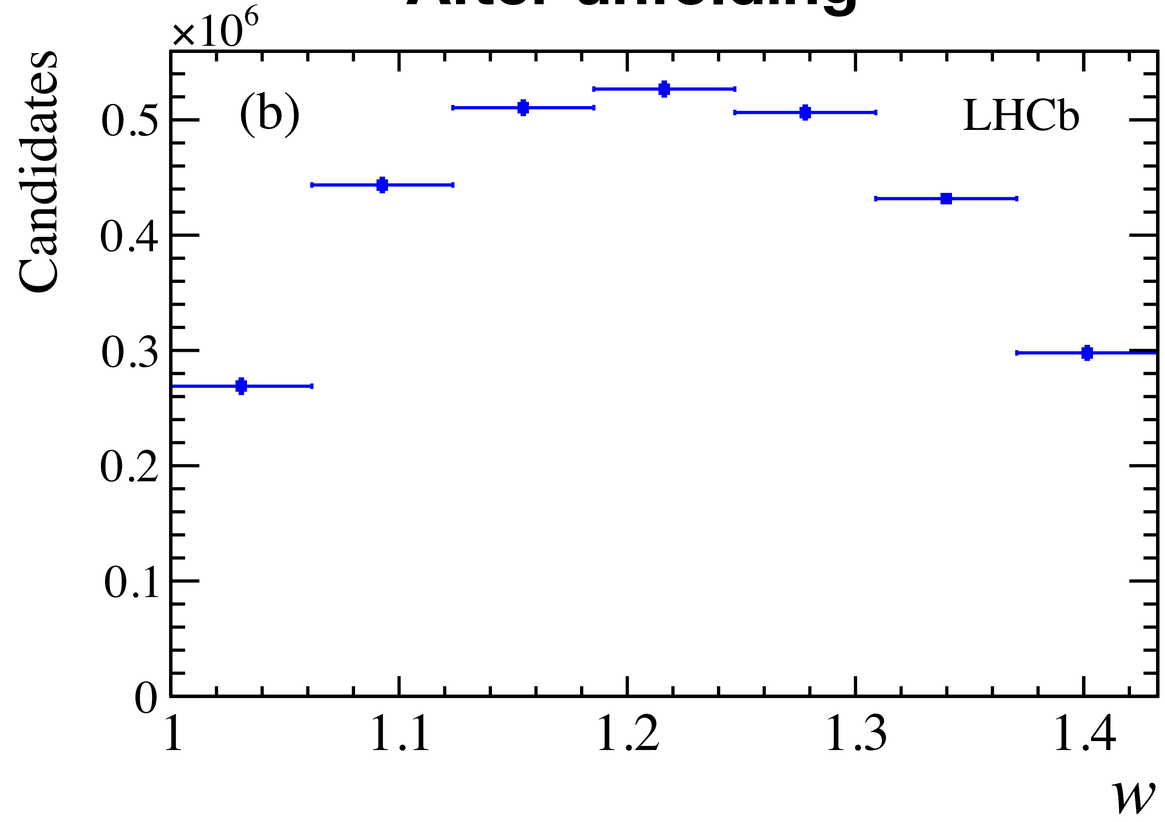
Unfolding

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

Before unfolding



After unfolding



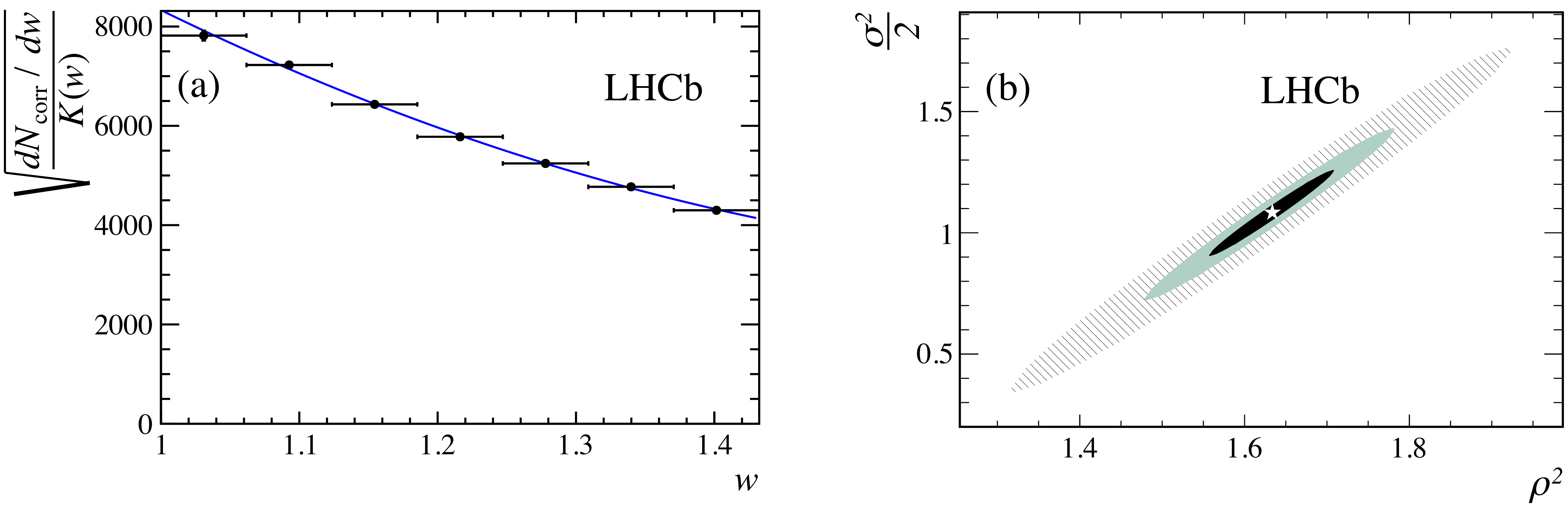
- Different regularisation parameters checked for systematic.
- Efficiency generally low at the edges of the phase-space, due to low momentum muon (trigger) or hadron (reconstruction/selection).

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

Phys. Rev. D 96, 112005 (2017)

Results

- Fit slope (ρ) and curvature (σ) of the Isgur-Wise function.

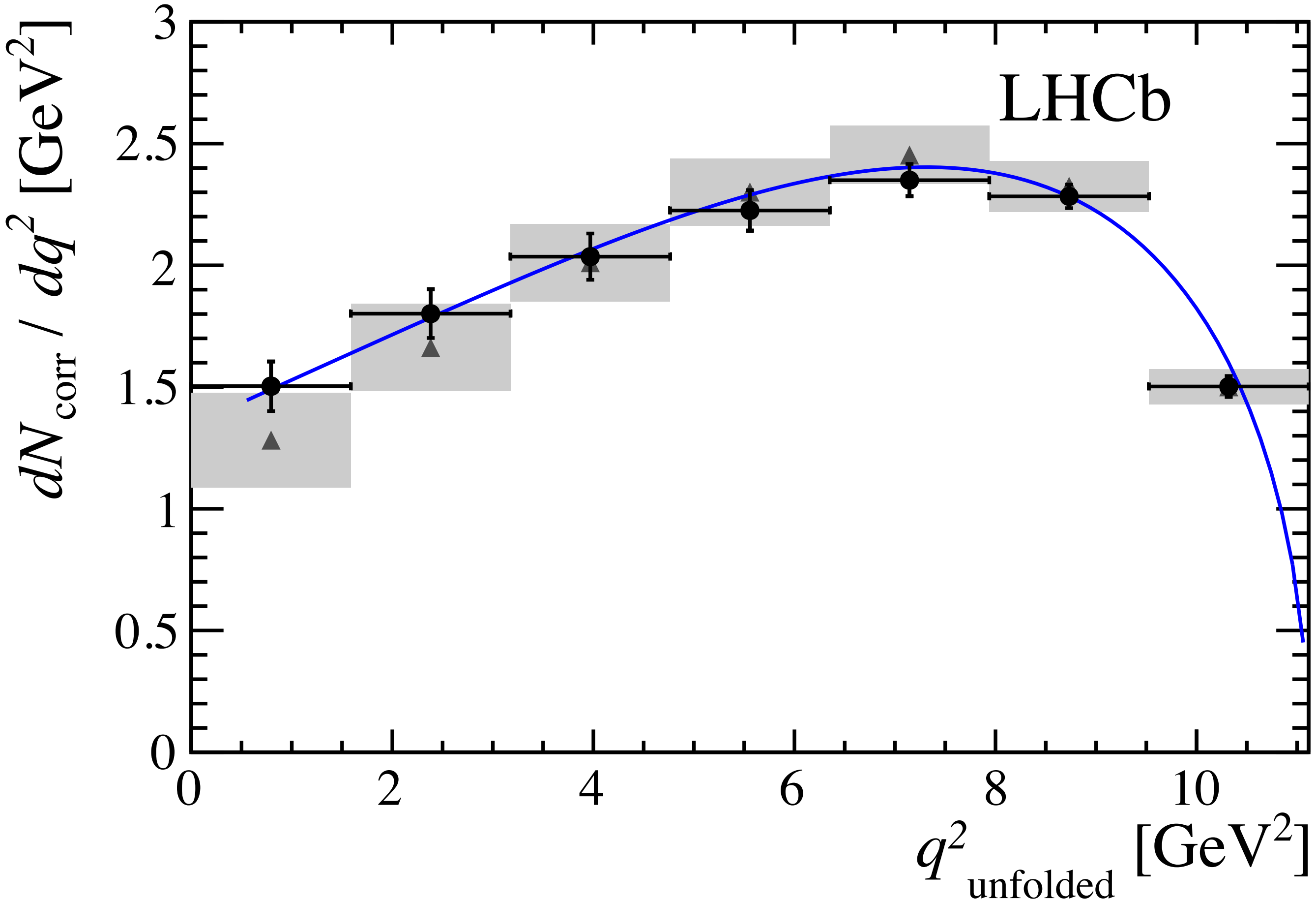


- Not possible to disentangle the two parameters with only the recoil information.

Phys. Rev. D 96, 112005 (2017)

Comparison with LQCD

- Also would like to compare with lattice predictions.

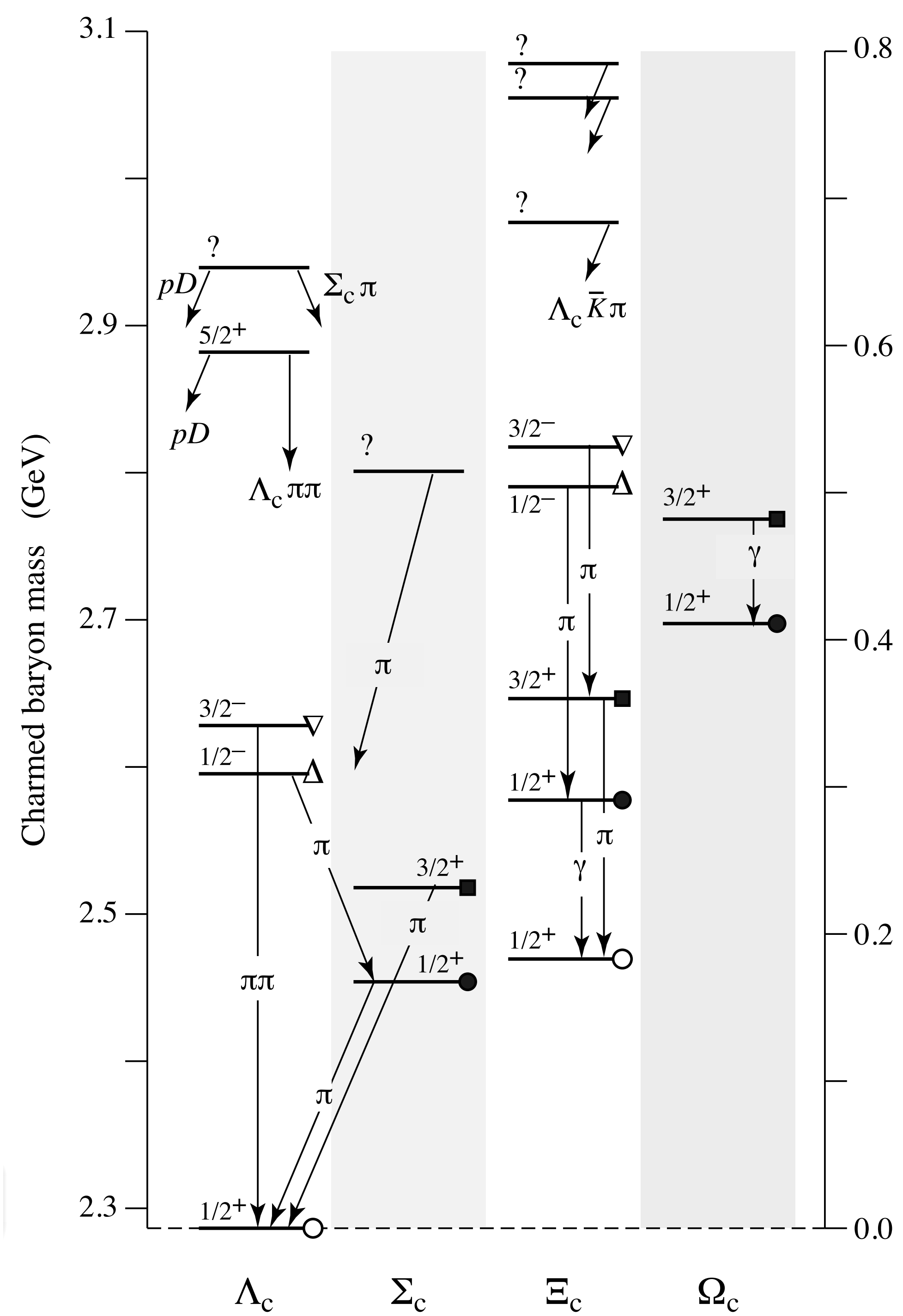


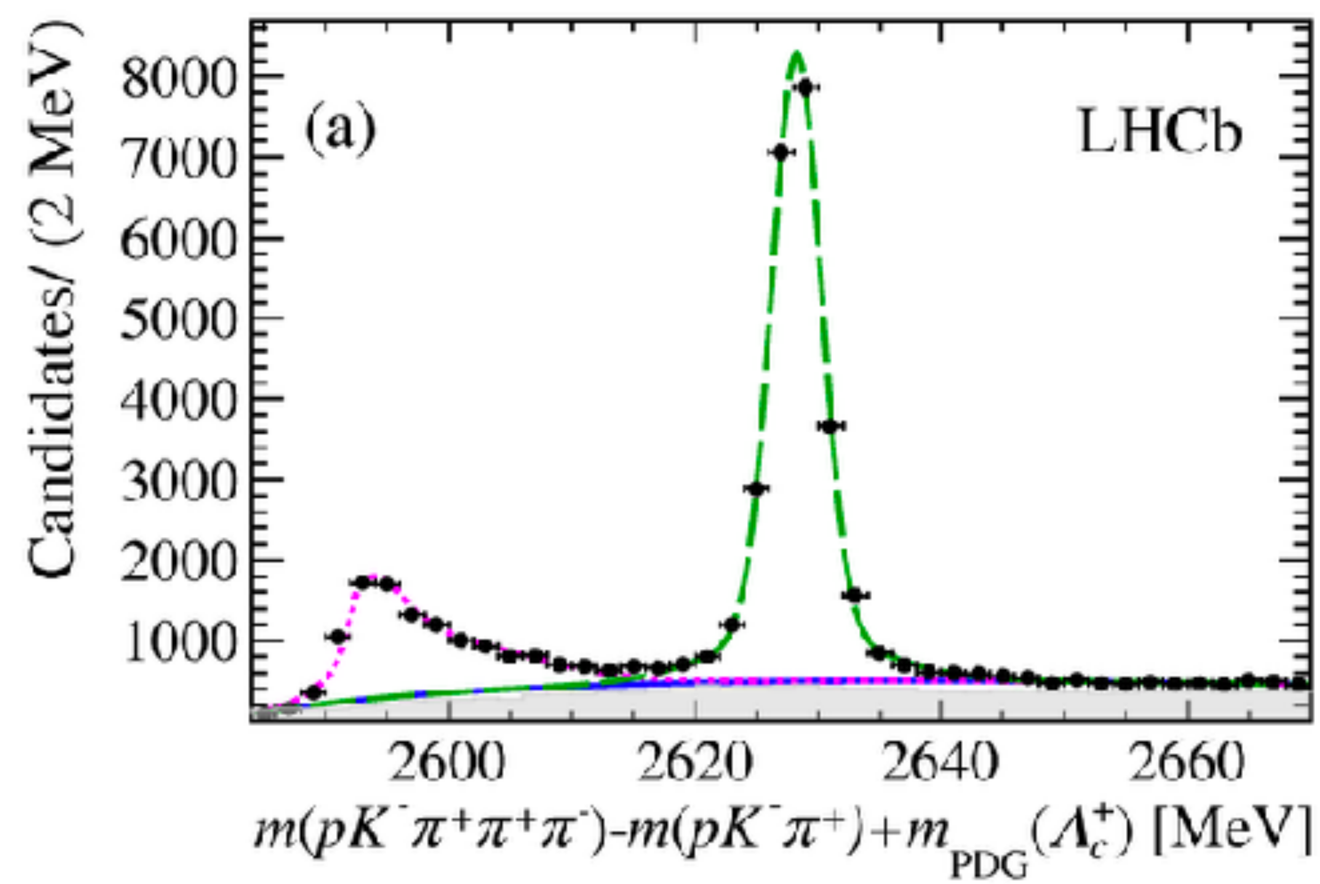
- Two fits performed:
  - Repeat of IW fit in q^2 bins
  - Fit single form factor parametrised with z-expansion.

- Fits look good, so data/LQCD/HQET agree.
  - Higher order corrections in HQET don't have large effect on shape.
- Next step would be to add angular information.

The excited state

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





- Plenty of signal, great opportunity to study.
  - Important for LFU determinations in baryon sector.

Böer et al, arXiv:1801.08367

$\Lambda_c{}^*$ differential decay rate

- Consider only the $\Lambda_b{}^0$ decay for now.

$$\frac{1}{\Gamma_0}\frac{\mathrm{d}^2\Gamma^J}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell} = \left(a_\ell^{(J)} + b_\ell^{(J)}\cos\theta_\ell + c_\ell^{(J)}\cos^2\theta_\ell\right)$$

- Strategy:
  - Decompose the decay rate and parameterise the resulting form factors.
  - Generate/fit toy datasets to assess experimental sensitivity.
  - Compute SM uncertainty on LU ratio $R_{\Lambda c^*}$

Böer et al, arXiv:1801.08367

Form factor decomposition

- Following the work from [7], decompose the $\Lambda_b^0 \to \Lambda_c^*$ decay rate in helicity basis.

$$\langle \Lambda_c(2595) | \bar{c}\gamma_\mu b | \Lambda_b \rangle = \sum_i f_i(q^2) \bar{u}^{\alpha}_{c,1/2}(k) \Gamma^{(i)}_{\mu\alpha}(p,k) u_b(p)$$

$$\langle \Lambda_c(2625) | \bar{c}\gamma_\mu b | \Lambda_b \rangle = \sum_i F_i(q^2) \bar{u}^{\alpha}_{c,3/2}(k) \Gamma^{(i)}_{\mu\alpha}(p,k) u_b(p)$$

- End up with 6 and 8 form factors for the 1/2 and 3/2 states.

- Up to 1/m corrections can reduce down to two IW functions using equations of motion.

    - Same functions describe both states.

[7] Leibovich, Stewardt, Phys. Rev. D 57, 5620 (1998)

IW parameterisation

- Inspired by work on the ground-state [8], we parameterise IW function with an exponential function.

$$\zeta(q^2)\Big|_{\text{exp}} \equiv \zeta(q^2_{\text{max}}) \exp\left[\rho\left(\frac{q^2}{q^2_{\text{max}}} - 1\right)\right] ,$$
$$\zeta_{\text{SL}}(q^2)\Big|_{\text{exp}} \equiv \zeta(q^2_{\text{max}})\delta_{\text{SL}} \exp\left[\frac{\rho_{\text{SL}}}{\delta_{\text{SL}}}\left(\frac{q^2}{q^2_{\text{max}}} - 1\right)\right] .$$

- As it is not expected to make an absolute measurement, we ignore the overall normalisation $\zeta(q^2_{max})$ (and it cancels in the LU ratio).

- The slopes ρ and also a relative normalisation for (sub-)leading functions.

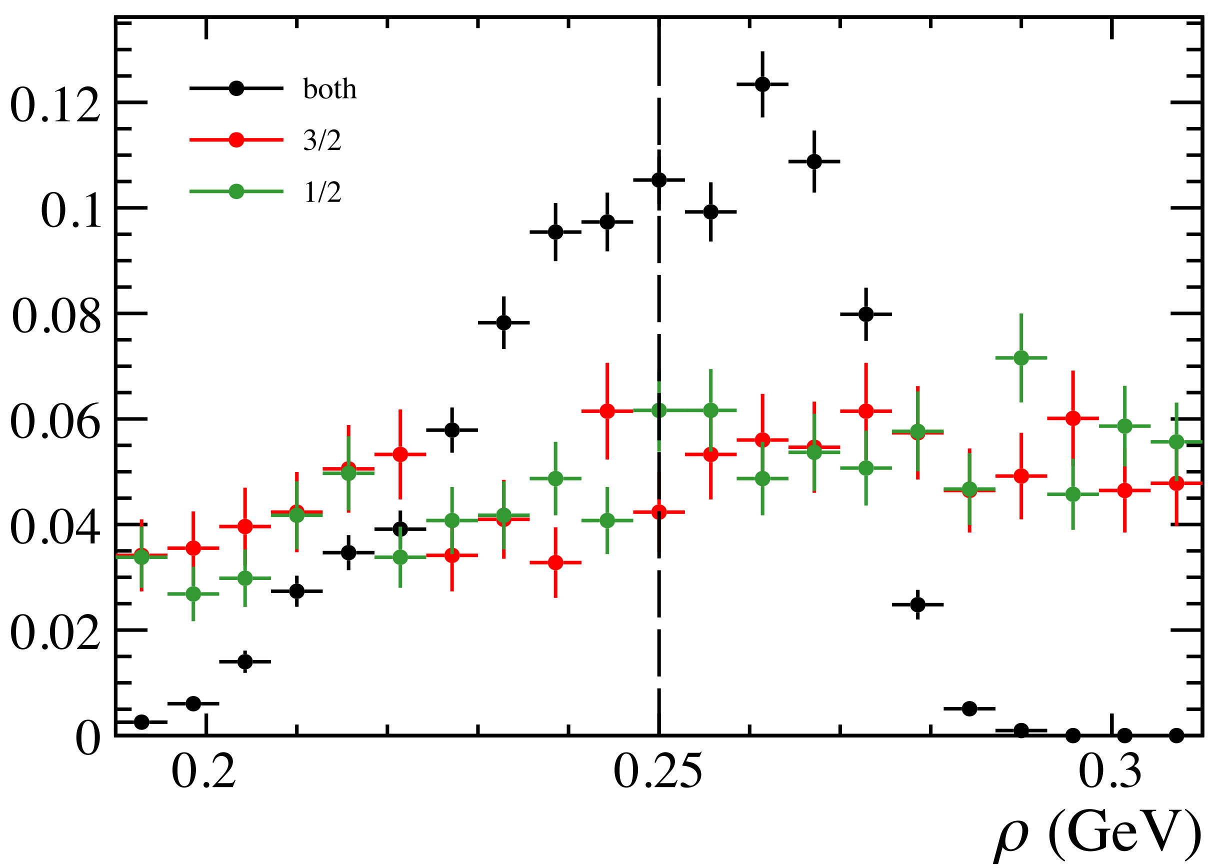
[8] Jenkins, Manohar, Wise, Nucl. Phys. B396:38-52,1993

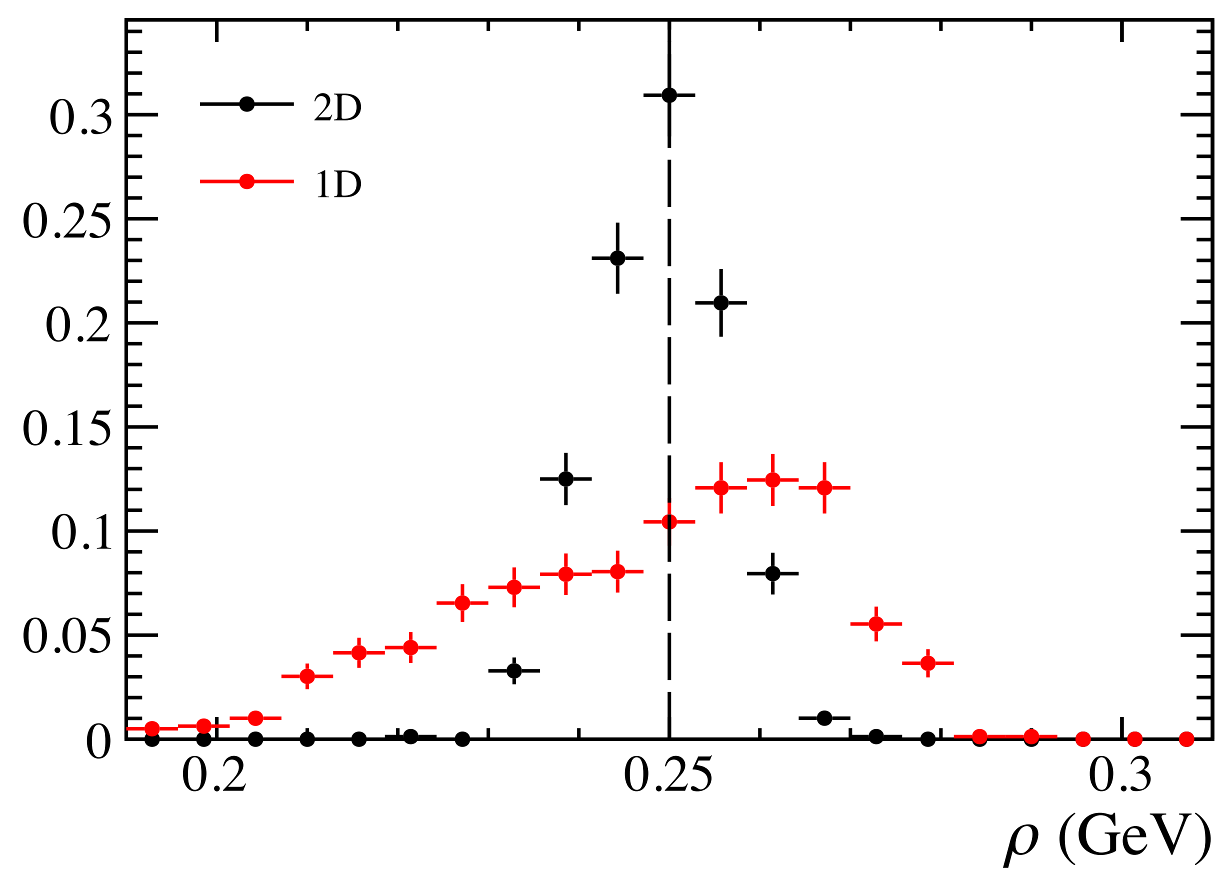
Böer et al, arXiv:1801.08367

Benefits of using all information

- Generate toys with LHCb yields and resolution, plot central values of ensemble.

- Benchmark point obtained from ZSCRs

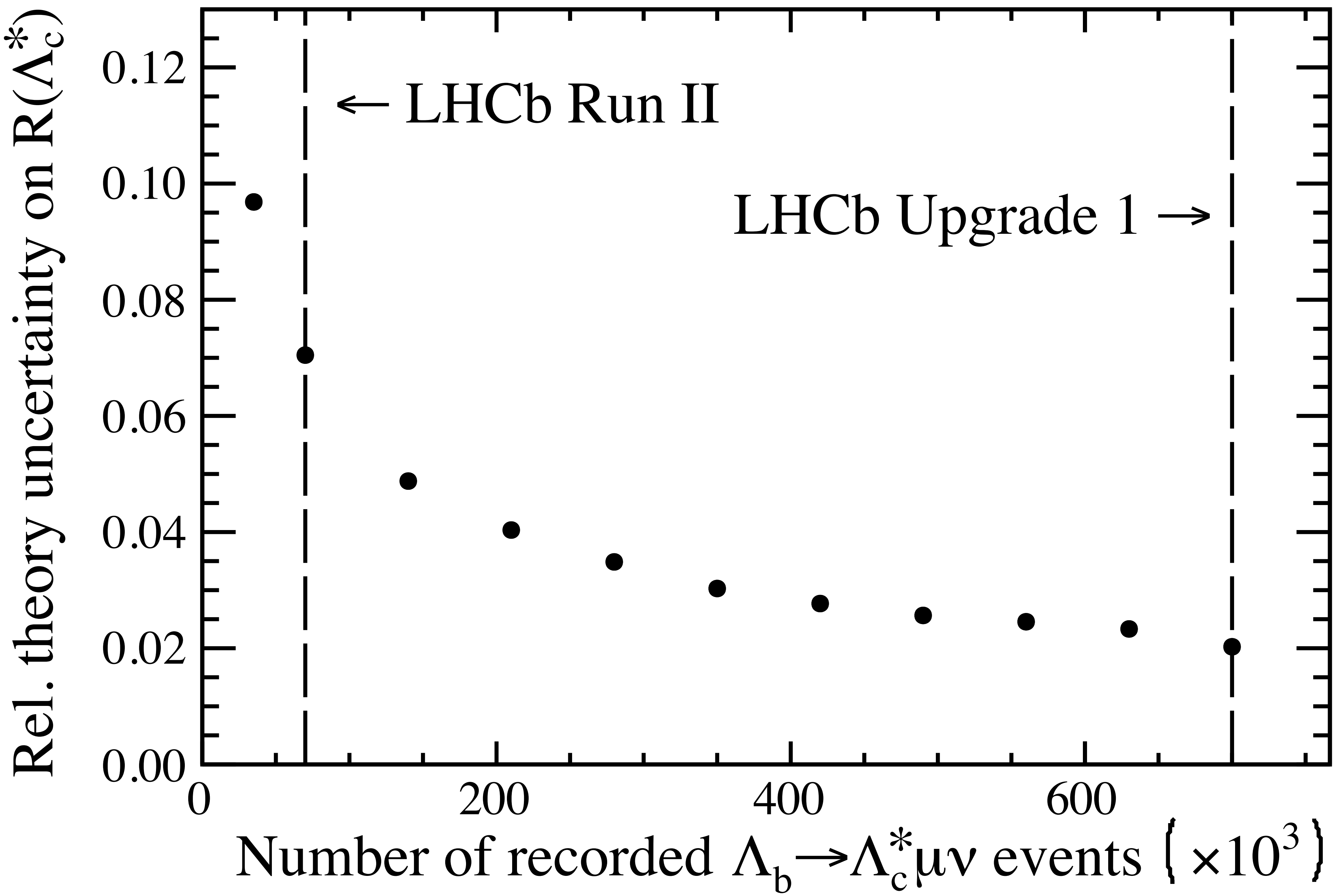




- Using both states and angular information key gets best sensitivity.

Böer et al, arXiv:1801.08367

Sensitivity to $R_{\Lambda c^*}$



Higher order corrections

- What about $1/m^2$ corrections?
- Conservative (?) estimate from [9] suggests 30% correction.
  - Leading to 7/8% on $R_{\Lambda c^*}$ ratios.
- Lattice input would be very useful indeed.
- Perhaps one could also get an idea by comparing the lattice/ HQET for the ground-state.

[9] Bigi, Gambino, Schacht, J. High Energ. Phys. (2017) 2017: 61

Summary

- The programme is moving with baryonic SL decays at LHCb.
- Still plenty of things to do, but hope to get similar SM uncertainty on LU ratios to mesonic versions.
- We are also working on the related LU ratios, but those are longer term.
- As always LQCD is an essential component in this.
    - Very much looking forward to any results on this.