Semileptonic $\Lambda_b \rightarrow \Lambda_c^{(*)} \mu \nu$ Decays

Marcello Rotondo

Laboratori Nazionali di Frascati

On behalf of the LHCb collaboration

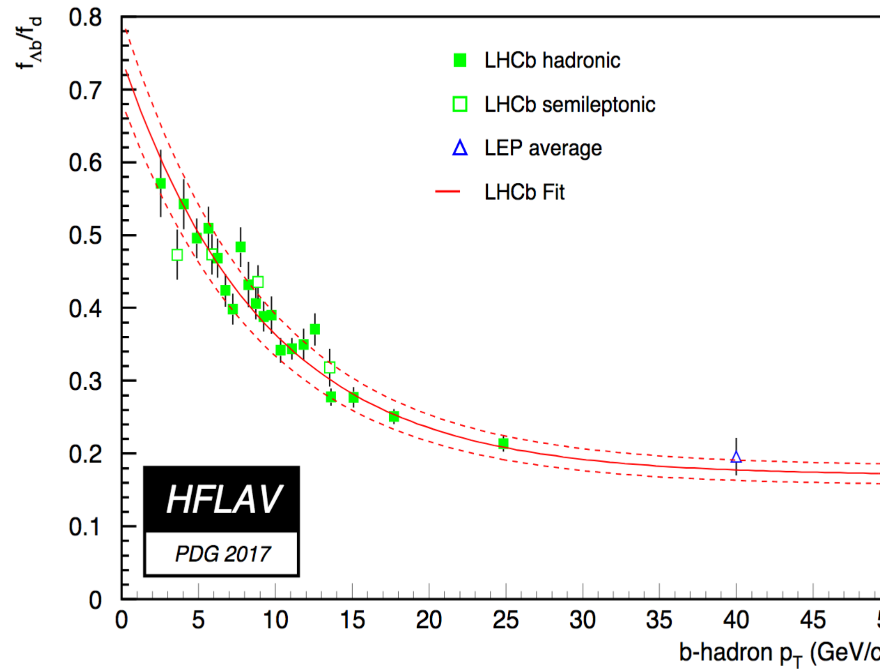
Why $\Lambda_b \to \Lambda_c \mu \nu$?

- $B \to D\mu\nu$ and $B \to D^*\mu\nu$ decays well studied at B-Factories
  - A lot of information about $B \to D^{**}\mu\nu$ and $B \to D\pi(\pi)\mu\nu$ also available
- Λ_b (***bdu***) have different spin structure and because the (***ud***) di-quark has j=0, HQET makes clean predictions

- Only few measurements (Delphi, CDFII) available for semileptonic Λ_b

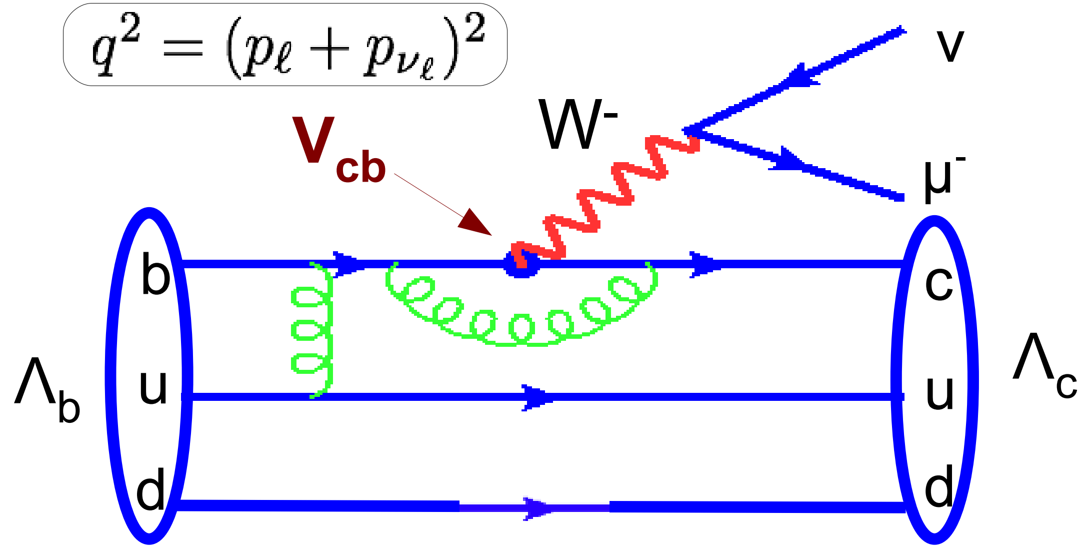
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	$(10.3 \pm 2.1)\%$
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$	$(6.2^{+1.4}_{-1.3})\%$
$\Lambda_c^+ \pi^+ \pi^- \ell^- \overline{\nu}_\ell$	$(5.6 \pm 3.1)\%$
$\Lambda_c(2595)^+ \ell^- \overline{\nu}_\ell$	$(7.9^{+4.0}_{-3.5}) \times 10^{-3}$
$\Lambda_c(2625)^+ \ell^- \overline{\nu}_\ell$	$(1.3^{+0.6}_{-0.5})\%$
$\Sigma_c(2455)^0 \pi^+ \ell^- \overline{\nu}_\ell$	
$\Sigma_c(2455)^{++} \pi^- \ell^- \overline{\nu}_\ell$	

- LHCb has the unique capability to study in detail the semileptonic Λ_b decays



$\Lambda_b \to \Lambda_c \mu\nu$

$$q^2 = (p_\ell + p_{\nu_\ell})^2$$



- Measure differential spectrum

$$\frac{d\Gamma}{dw} = GK(w)\xi_B^2(w)$$

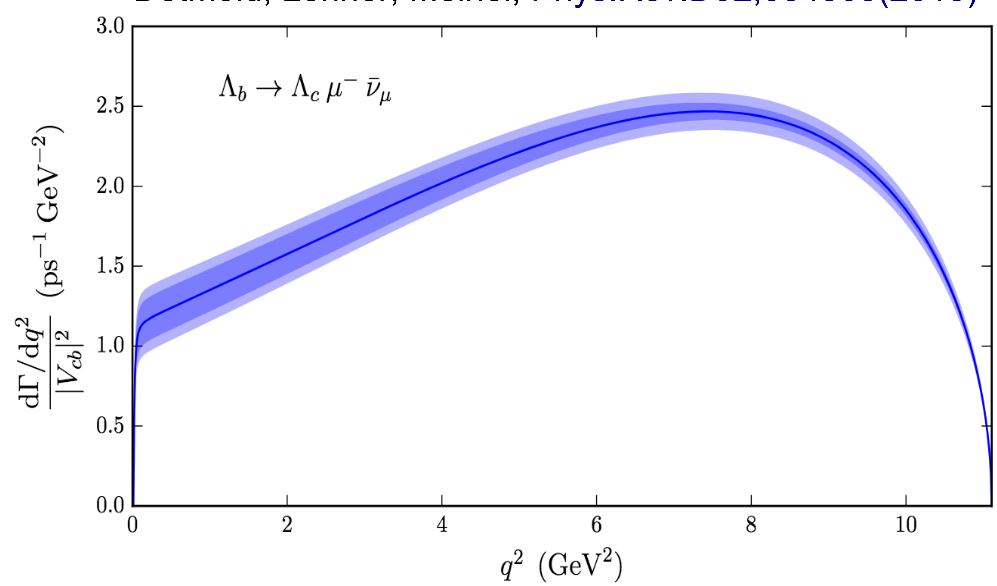
$$w = v_{\Lambda_b} \cdot v_{\Lambda_c} = \frac{m_{\Lambda_b}^2 + m_{\Lambda_c}^2 - q^2}{2m_{\Lambda_b} m_{\Lambda_c}}$$

- Extract information on function $\xi_B(w)$ assuming parameterizations based on phenomenological models or simple expansion around w=1

$$\xi_B(w) = 1 - \rho^2(w-1) + \frac{1}{2}\sigma^2(w-1)^2 + \cdots$$

- Check precise lattice results
- Test HQET predictions in baryons
- First step toward a precise $|V_{cb}|$ from baryon decays

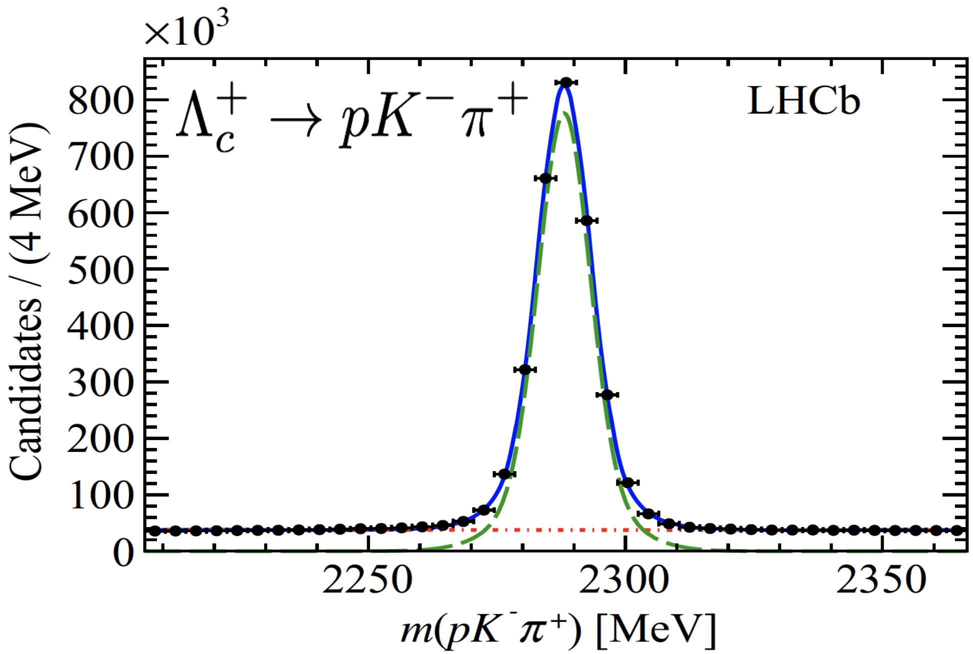
Detmold, Lehner, Meinel, Phys.Rev.D92,034503(2015)



$\Lambda_b \to \Lambda_c \mu \nu$: yields and backgrounds

PRD96,112005(2017)

- Run1 data: 3fb^{-1} $\quad N(\Lambda_c^+ \mu^-) = (2.74 \pm 0.02) \times 10^6$

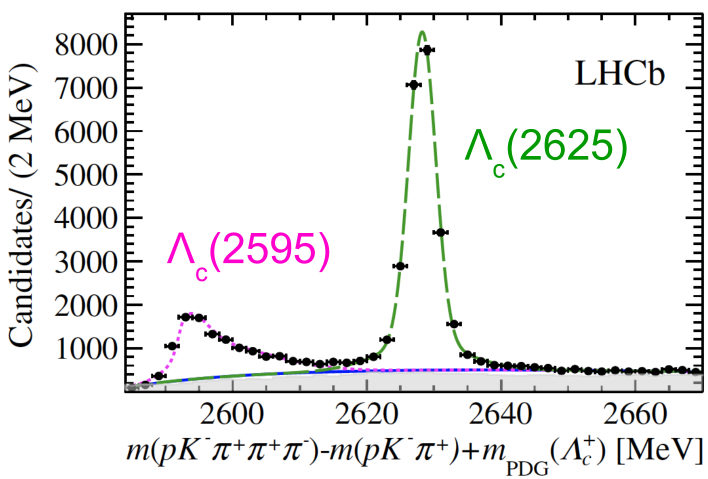


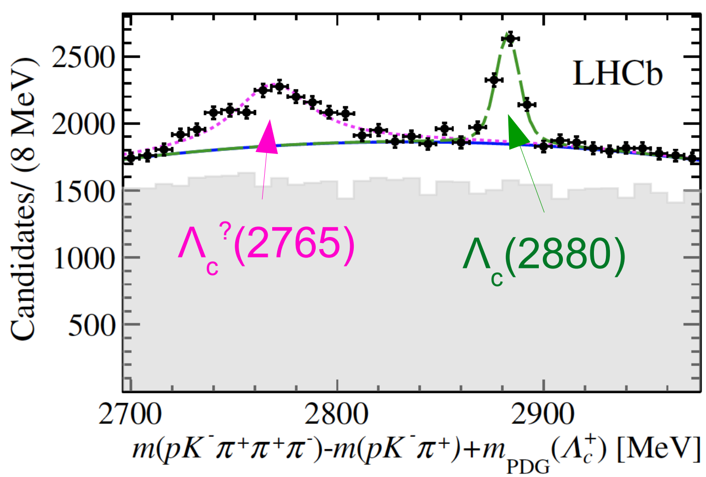
Very large and clean sample of $\Lambda_b \to \Lambda_c\, \mu\, \nu\, X$

Main peaking backgrounds:

- $\Lambda_b \to \Lambda_c^*\, \mu\nu$ with $\Lambda_c^* \to \Lambda_c\pi^+\pi^-$ and $\Lambda_c\pi^0\pi^0$
  Fit on data using $\Lambda_c\pi^+\pi^-$ decay which covers 2/3 of the Λ_c^* decays

- $\Lambda_b \to \Sigma_c^{++}\pi\, \mu\nu$ and $\Sigma_c^0\pi\, \mu\nu$ with $\Sigma_c \to \Lambda_c\pi$
  From data reconstructing $\Sigma_c \to \Lambda_c\pi$





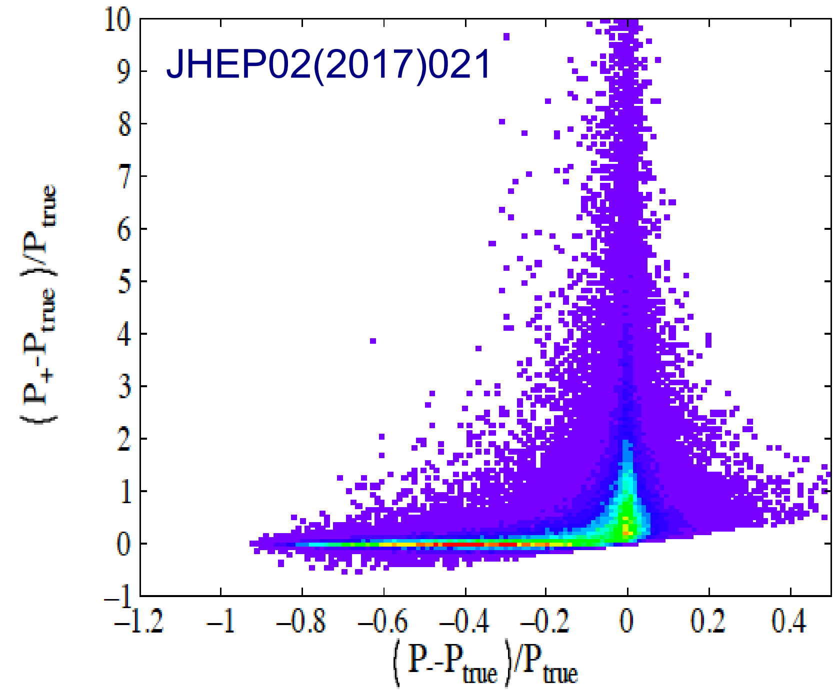
Measured raw yields

$\Lambda_c(2595)^+\mu^-\bar{\nu}_\mu$	8569 ± 144
$\Lambda_c(2625)^+\mu^-\bar{\nu}_\mu$	22965 ± 266
$\Lambda_c(2765)^+\mu^-\bar{\nu}_\mu$	2975 ± 225
$\Lambda_c(2880)^+\mu^-\bar{\nu}_\mu$	1602 ± 95

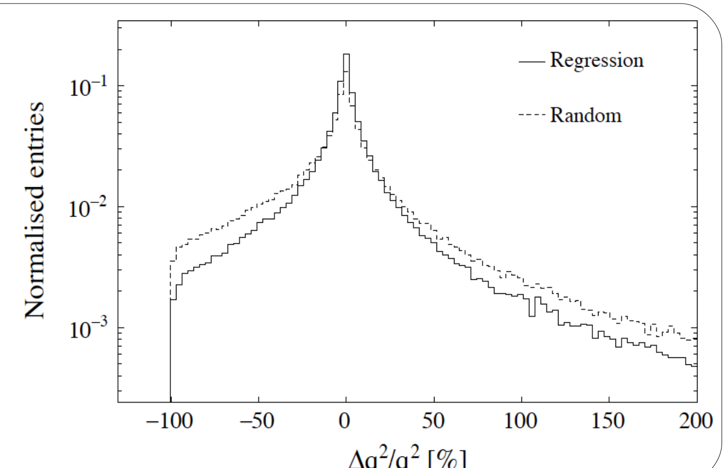
Significant yields with excited states: opportunity to study them

Reconstruction of the q^2

- The knowledge of the Λ_b momentum P_b is needed to measure $q^2=(P_b - P_c)^2$
- No constraints from beam energy as at B-Factories
  - Hypothesis of just 1-neutrino missing and the well-measured Λ_b flight direction gives the momentum with a 2-fold ambiguity, P_+ and P_-
  - Without selection both solutions have same chances to be the correct
  - After all selections the solution with smaller P_b momentum is more often the correct one



- Ciezarek et al JHEP02(2017)021
  - The q^2 resolution can be improved exploiting other information as decay length and angle with respect to the beam line
  - Important when angular variables will be considered



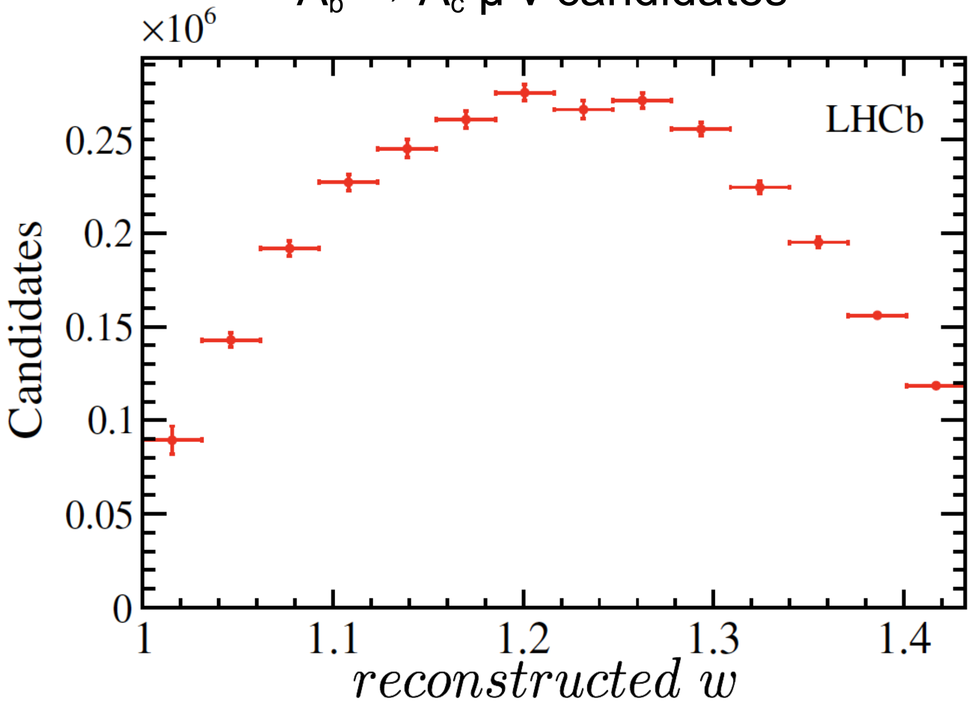
Extraction of the q^2 spectrum

$$w = v_{\Lambda_b} \cdot v_{\Lambda_c} = \frac{m^2_{\Lambda_b} + m^2_{\Lambda_c} - q^2}{2 m_{\Lambda_b} m_{\Lambda_c}}$$

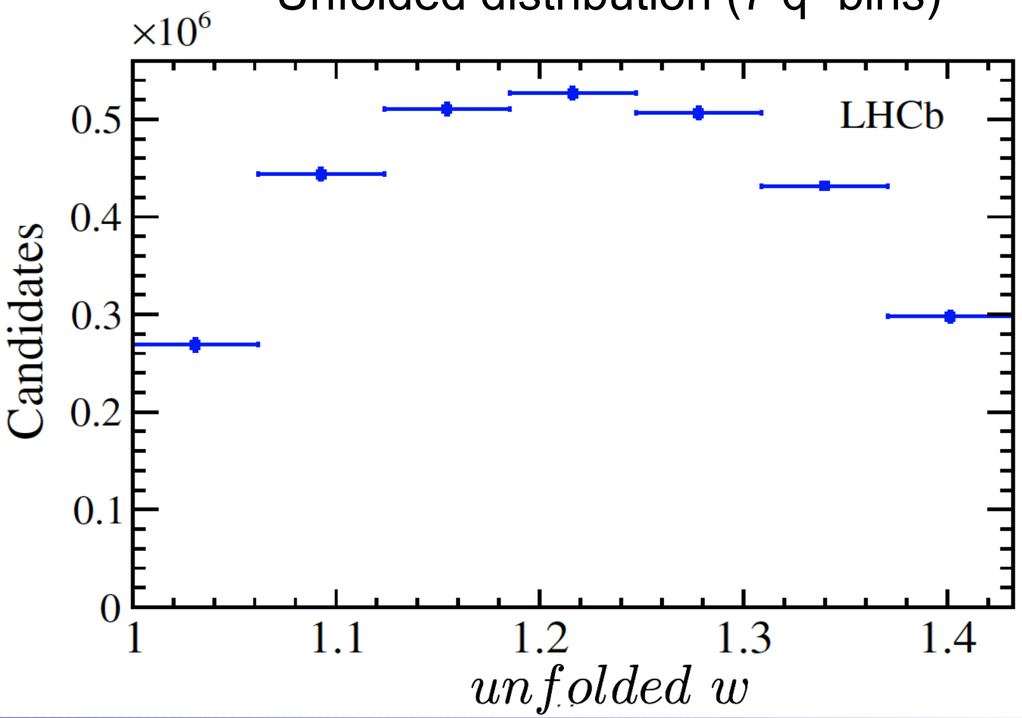
- Sample of $\Lambda_b \rightarrow \Lambda_c \mu \nu X$ extracted in 14 bins of q^2 (take lower $p_{\Lambda b}$ solution)
- Correct for feed-down from peaking backgrounds in each bin
- Correct for selection efficiency
- Distribution unfolded with SVD technique (regularization parameter chosen from simulation)

PRD96,112005(2017)

Background subtracted
$\Lambda_b \rightarrow \Lambda_c \mu \nu$ candidates

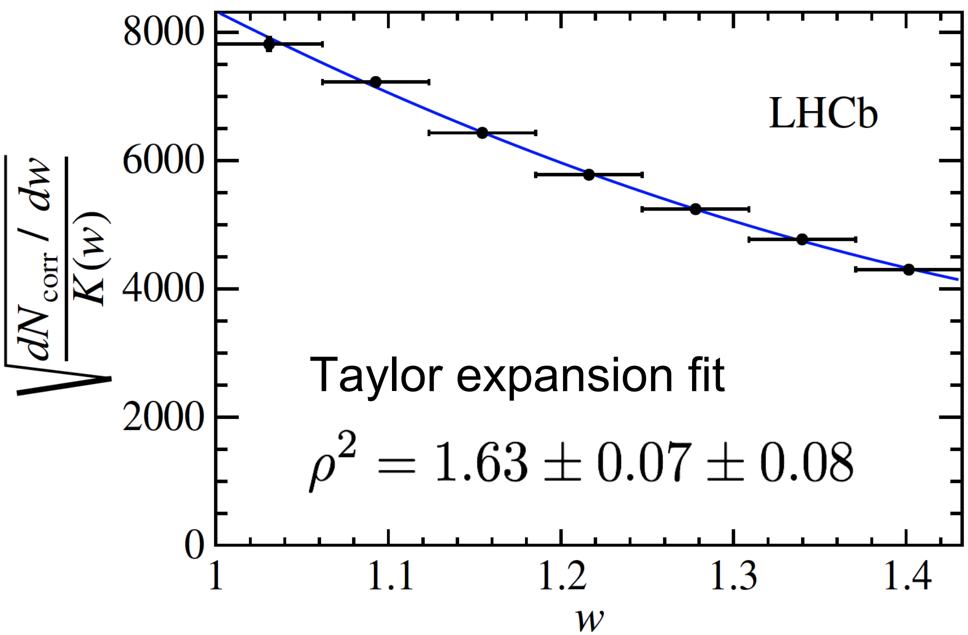


Unfolded distribution (7 q^2 bins)



$\Lambda_b \to \Lambda_c \mu\nu$: results

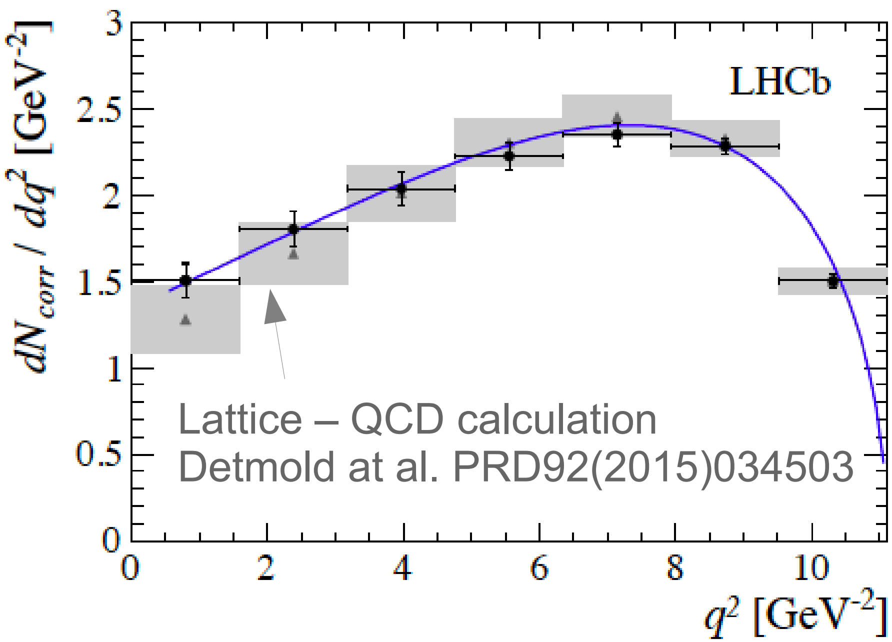
PRD96,112005(2017)



Shape	ρ^2	σ^2
Exponential*	1.65 ± 0.03	2.72 ± 0.10
Dipole*	1.82 ± 0.03	4.22 ± 0.12
Taylor series	1.63 ± 0.07	2.16 ± 0.34

Corr = 94%

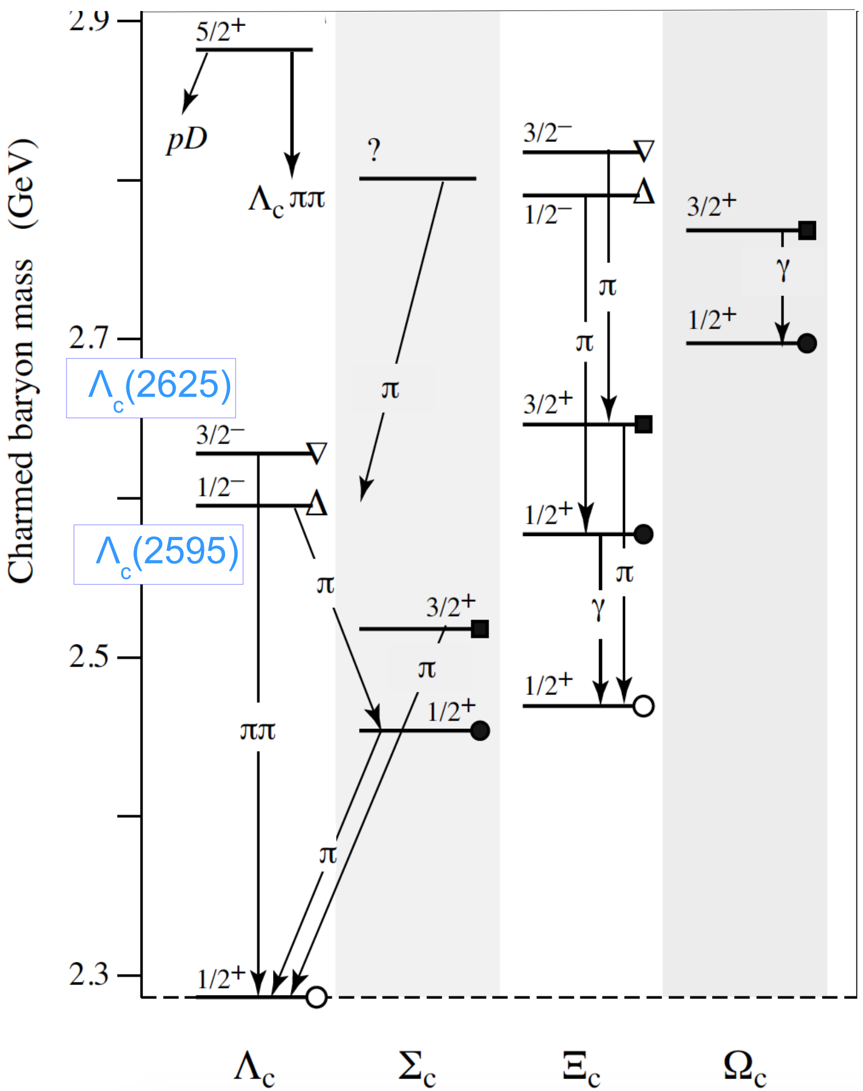
- Different parameterizations have good fit quality: data/HQET predictions agree
- Knowledge of $\Lambda_b \to \Lambda_c$ form-factors crucial for $R(\Lambda_c)$
- A suitable normalization would allow $|V_{cb}|$ extraction
- Open the route to measurements of FF in other B-hadrons



- Comparison with recent lattice calculation shows good agreement
  - Support the lattice calculation used in the $|V_{ub}|/|V_{cb}|$ measurement
- In future further L-QCD calculations would be really desirable!

Excited states $\Lambda_c^{1/2}$ and $\Lambda_c^{3/2}$

- Interesting opportunities to study $\Lambda_b \to \Lambda_c^* \mu\nu$ in particular the copious $\Lambda_b \to \Lambda_c(2595) \mu\nu$ and $\Lambda_b \to \Lambda_c(2625) \mu\nu$ channels



- Interesting in near future for LFU test with Λ_b semi-tauonic decays
  - Reduced feed-down from higher order excited states
  - $\Lambda_c^* \to \Lambda_c \pi^+ \pi^-$, di-pion allows a clean experimental signature
- Theoretical papers on these decays
  - Leibovich, Stewart PRD57(1998)5620
  - Pervin et al. PRC72(2005)035291
  - Gutsche et al. arXiv:1807.11300

- Sensitivity in LHCb to the form factors in these decays has been investigated in Böer et al. JHEP06(2018)155

$\Lambda_b \to \Lambda_c^* \mu\nu$: LHCb sensitiviy

- Böer et al. JHEP06(2018)155

- Decomposing the $\Lambda_b \to \Lambda_c^J$ μν decay rate in helicity basis
  - 6 form factors for 1/2 state
  - 8 form factors for 3/2 state
- Up to 1/m corrections can be reduced to two independent Isgur-Wise functions
  - Interestingly the same functions describe both states
- For unpolarized Λ_b the differential decay rate is

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

Coefficients a,b,c depend on J and Lepton kind

- Strategy for the sensitivity study in LHCb
  - Parametrize the relevant form-factors with a phenomenological model
  - Generate and fit toys at different luminosity scaling properly the yields extracted in LHCb
    - Considering the resolution on q^2 and $\cos\theta_\ell$ as in JHEP02(2017)021

FF parameters sensitivity

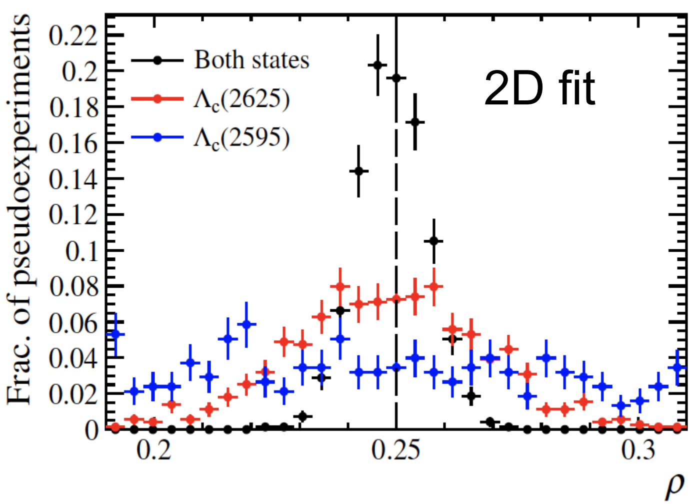
- Böer et al. JHEP06(2018)155

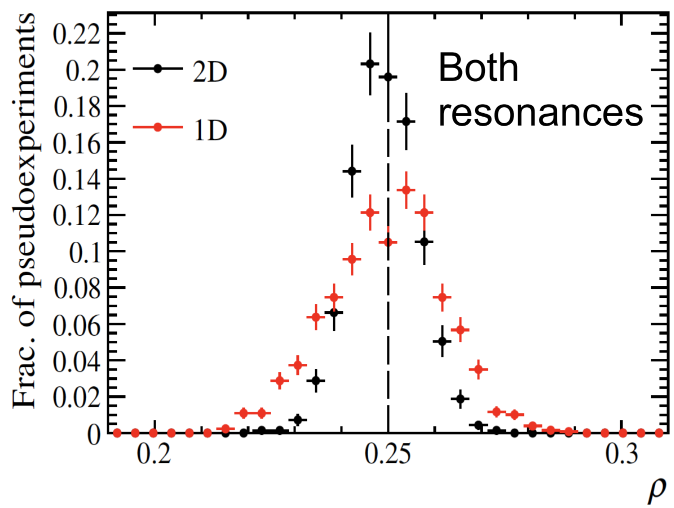
- Form-factors parameterized with exponential functions

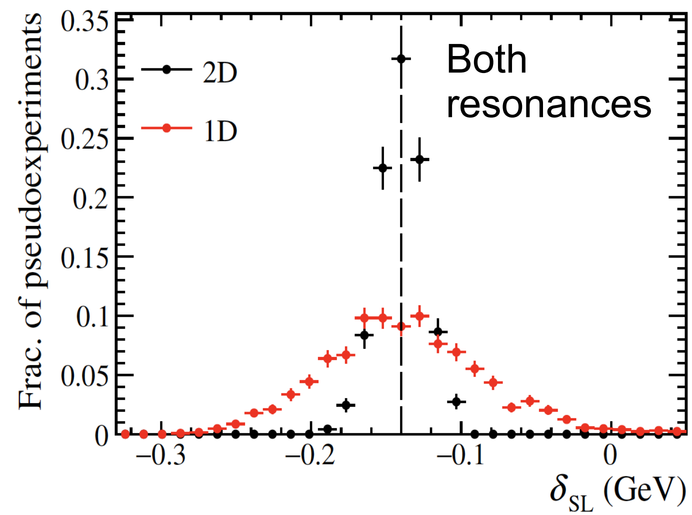
$$\zeta(q^2)\Big|_{exp} \equiv \zeta(q^2_{max}) \exp\left[\rho\left(\frac{q^2}{q^2_{max}}-1\right)\right]$$

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

- Fits with different configurations:
  - Separately for $\Lambda_c^{1/2}$ and $\Lambda_c^{3/2}$
  - 1-Dimensional q^2
  - 2-Dimensional combined q^2 and $\cos\theta_\ell$





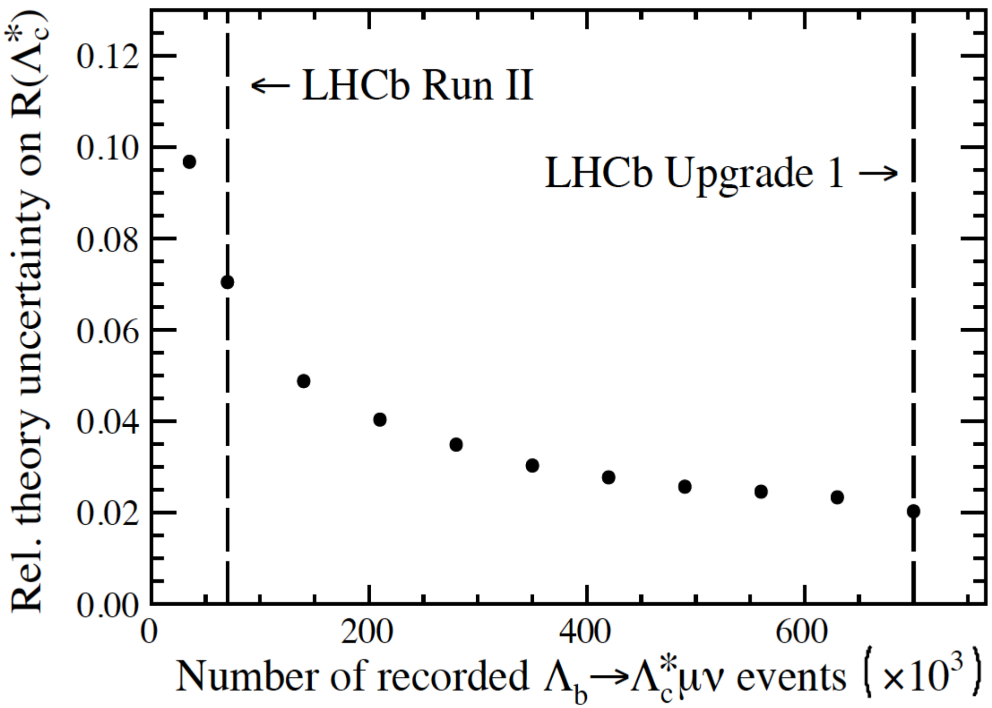


Sensitivity corresponding to the data available at the end of Run2 ~20K $\Lambda_c^{1/2}$ and ~50K $\Lambda_c^{3/2}$

- Best sensitivity with simultaneous 2D fit on both resonances: analysis ongoing in LHCb

Expectations for R(Λ_c*)

- Böer et al. JHEP06(2018)155



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

- The decay into ground state is more favourable because of the large BF, higher efficiency
- With higher statistics the excited states would allow better control of the systematics due to the peaking backgrounds

- From recent calculations from Gutsche et al. arXiv:1807.11300

	$\Lambda_c^+(\frac{1}{2}^+)$	$\Lambda_c^{*+}(\frac{1}{2}^-)$	$\Lambda_c^{*+}(\frac{3}{2}^-)$
e	6.80 ± 1.36	0.86 ± 0.17	0.17 ± 0.03
μ	6.78 ± 1.36	0.85 ± 0.17	0.17 ± 0.03
τ	2.00 ± 0.40	0.11 ± 0.02	0.018 ± 0.004
$R(\Lambda_c^{(*)})$	0.30 ± 0.06	0.13 ± 0.03	0.11 ± 0.02

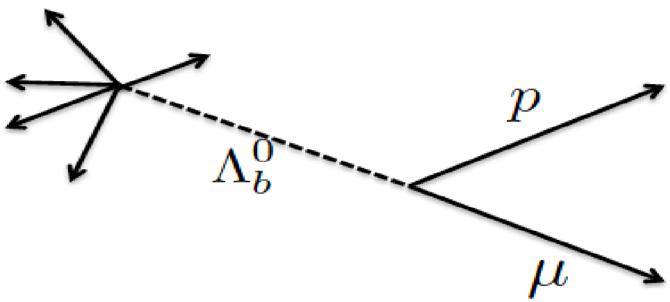
Outlook

- Properties of semileptonic decays of b-baryons can be studied in LHCb with high precision
- Great opportunities
  - Measurements of CKM parameters, LFU tests
  - hope to get soon similar/better level of knowledge as in B meson decays
- Crucial interplay with theorists
  - L-QCD is an essential ingredient but it usually requires time
  - Predictions using other approaches are of course very welcome
- News from baryons in the next months!

BACKUP

$|V_{ub}|$ at LHCb

- B-baryons provide complementary informations to B-mesons
- Copious production of Λ_b

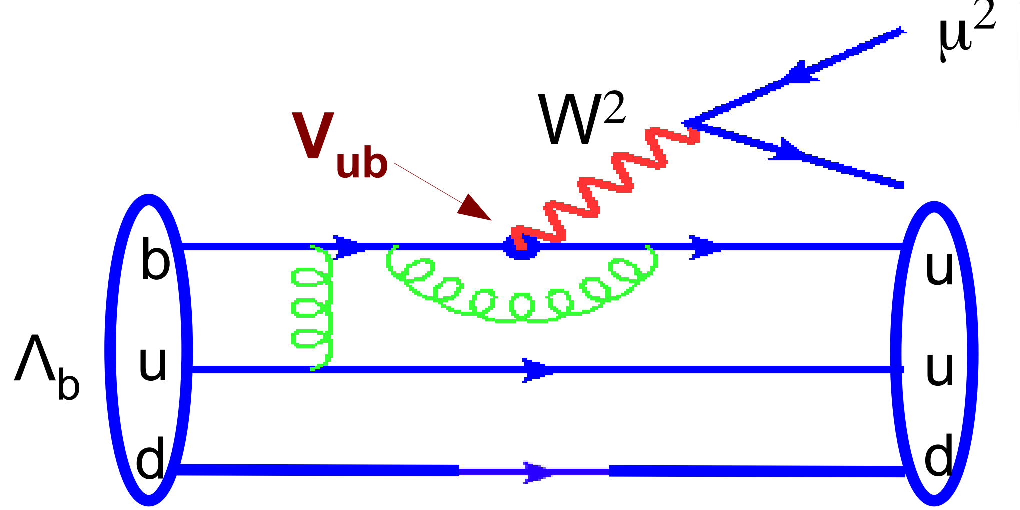


- Kinematic constraints allow the determination of the $p_{\Lambda b}$ (modulo 2-fold ambiguity)
- Large background from $\Lambda_b \rightarrow \Lambda_c \mu\nu$
- LHCb determines (in the high q^2 region) the ratio

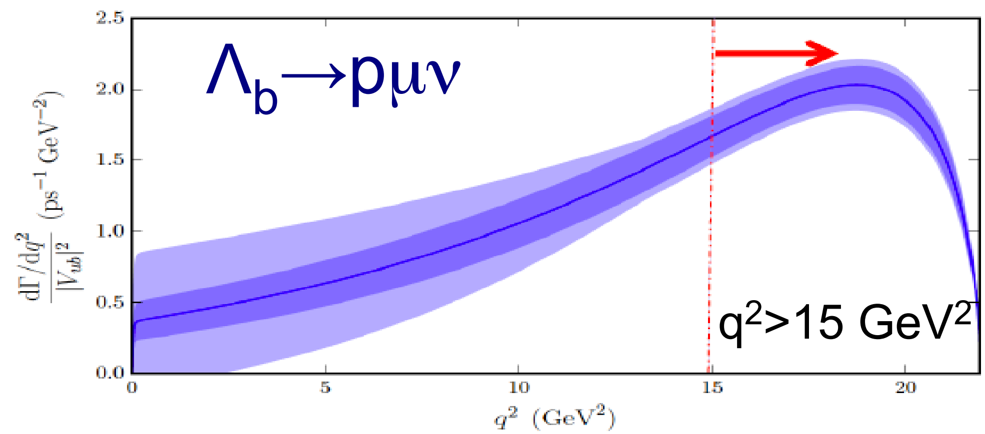
$$R_{exp} = \frac{\mathcal{B}(\Lambda_b \rightarrow p\mu\nu)}{\mathcal{B}(\Lambda_b \rightarrow \Lambda_c \mu\nu)}$$

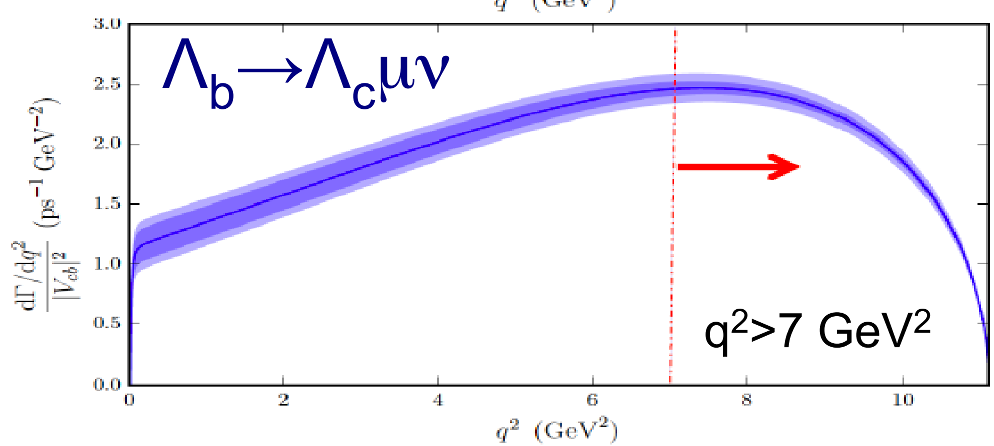
Signal

Normalization



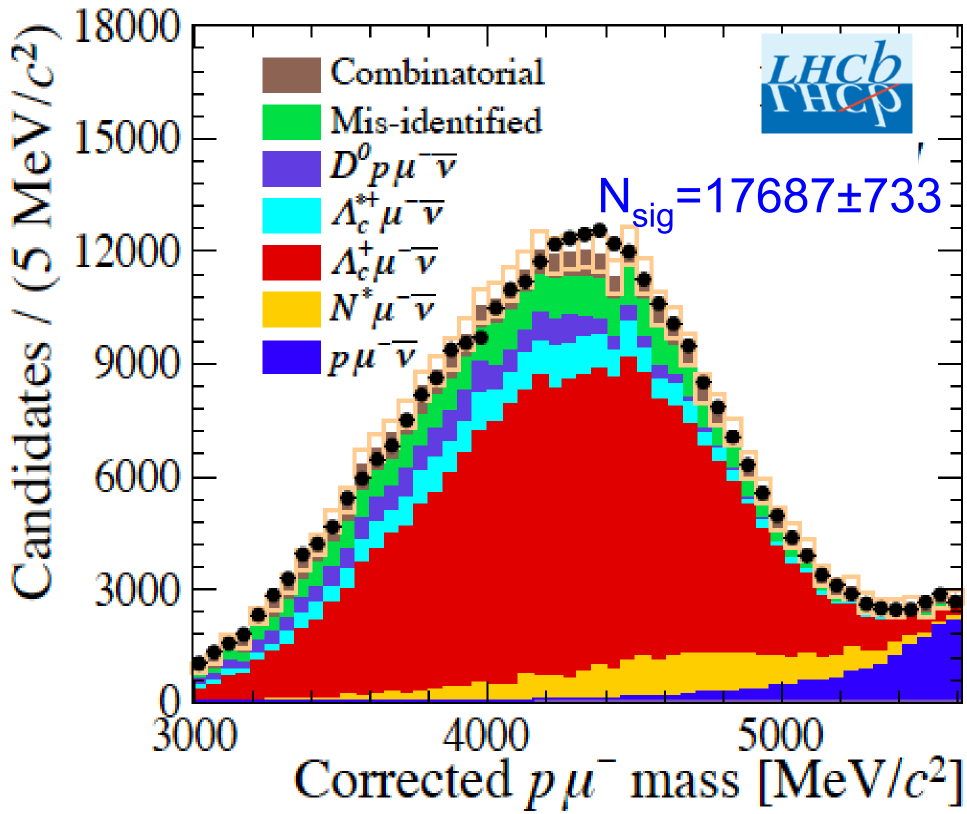
- Precise F.F.calculation on L-QCD
  - Detmold et al PRD92(2015)034503





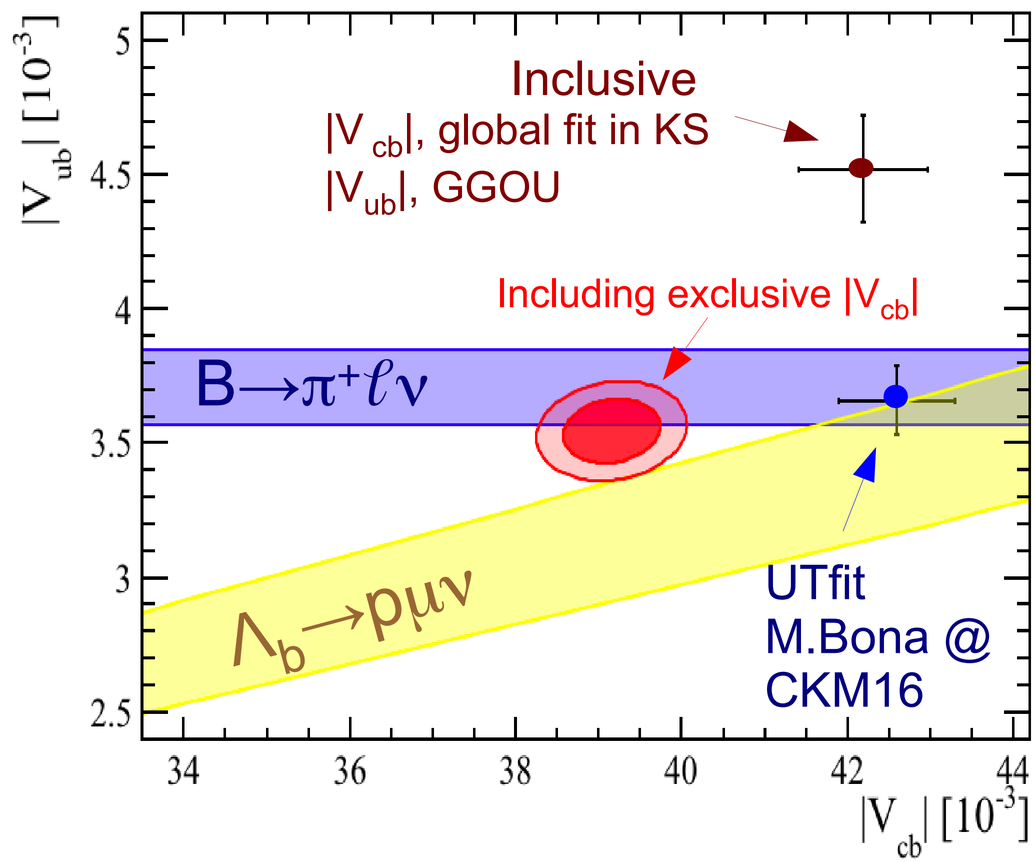
$\Lambda_b \rightarrow p\mu\nu$ signal & $|V_{ub}|$

$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$



$$\frac{|V_{ub}|}{|V_{cb}|} = 0.080 \pm 0.004_{Exp.} \pm 0.004_{F.F.}$$

σ_{tot}=7%



$$R = \frac{\mathcal{B}(\Lambda_b \rightarrow p\mu\nu)_{q^2>15\ GeV^2}}{\mathcal{B}(\Lambda_b \rightarrow \Lambda_c\mu\nu)_{q^2>7\ GeV^2}} = (0.95 \pm 0.04 \pm 0.07) \times 10^{-2}$$

Systematics dominated by BF($\Lambda_c \rightarrow pK\pi$)=(6.46 ± 0.24)% HFLAV using BESIII-Belle measurements

New global picture ?