

# Measurement of $V_{ub}$ at LHCb

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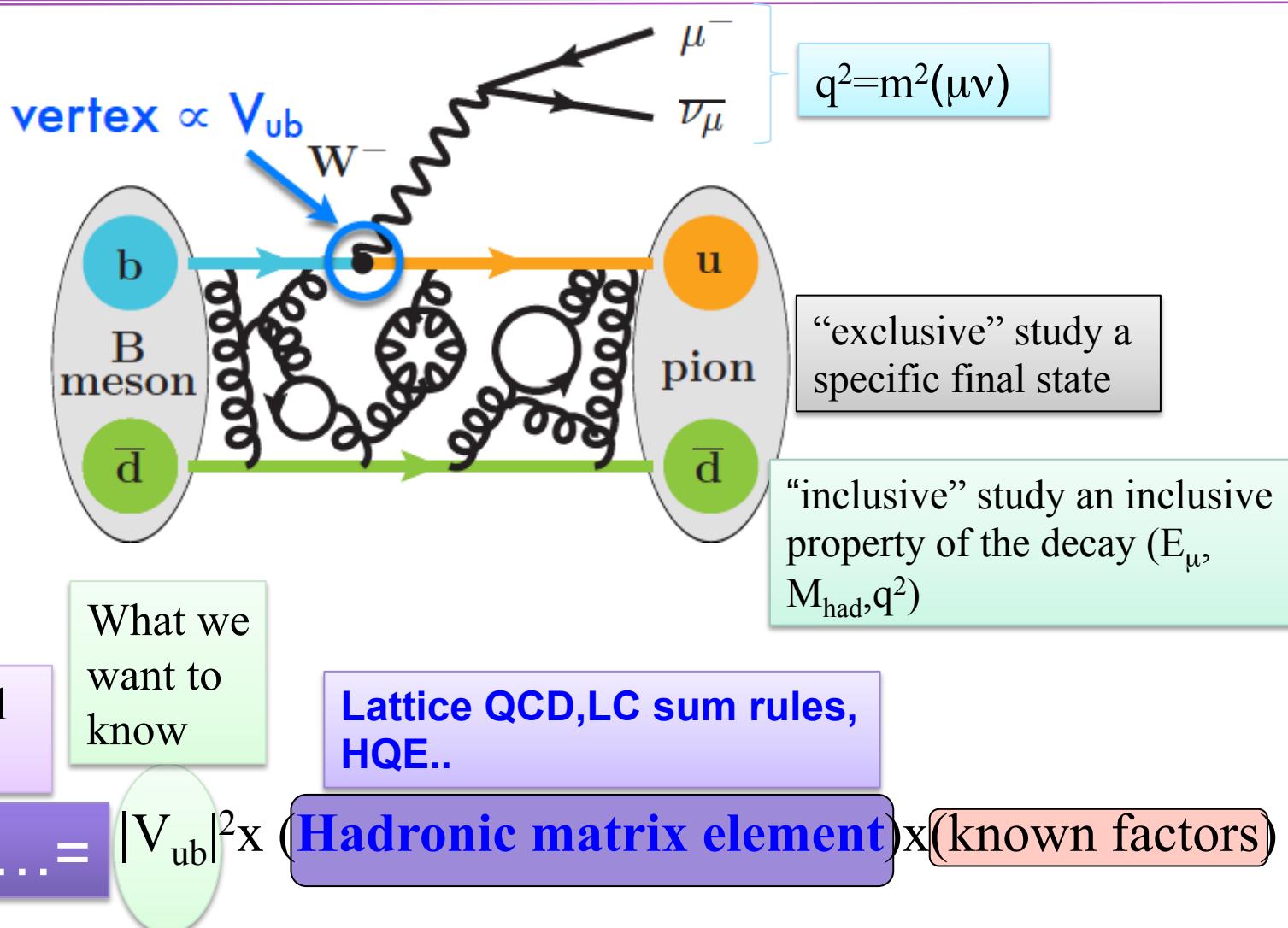
Current status and future perspectives

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On behalf of the LHCb collaboration



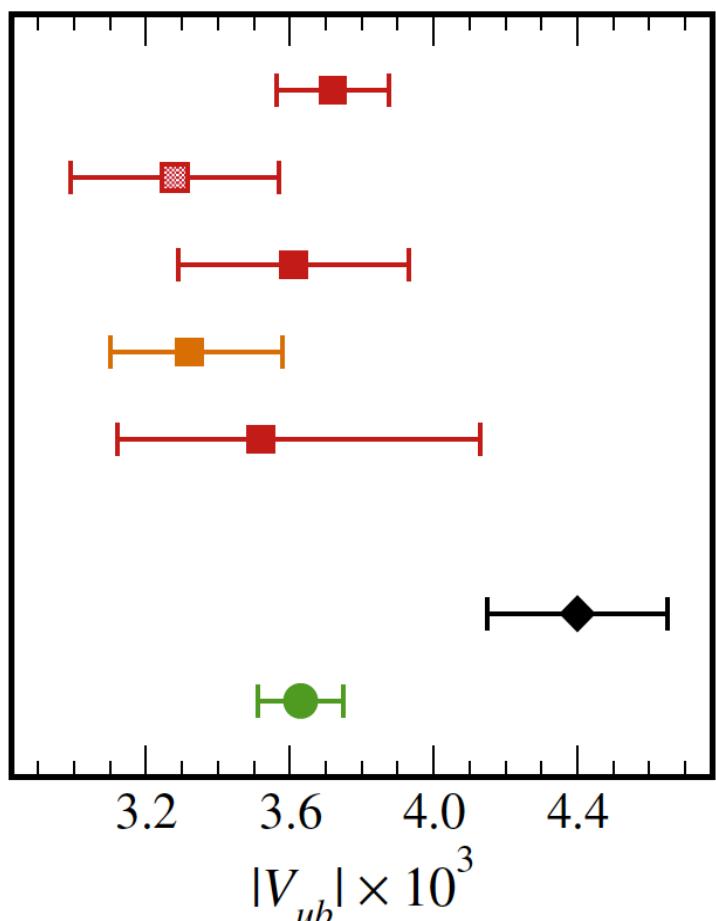
# $V_{ub}$ and semileptonic $b$ decays



Experimental observables

# The $V_{ub}$ tension

- 3  $\sigma$  discrepancy between inclusive and exclusive determinations of  $V_{ub}$ .



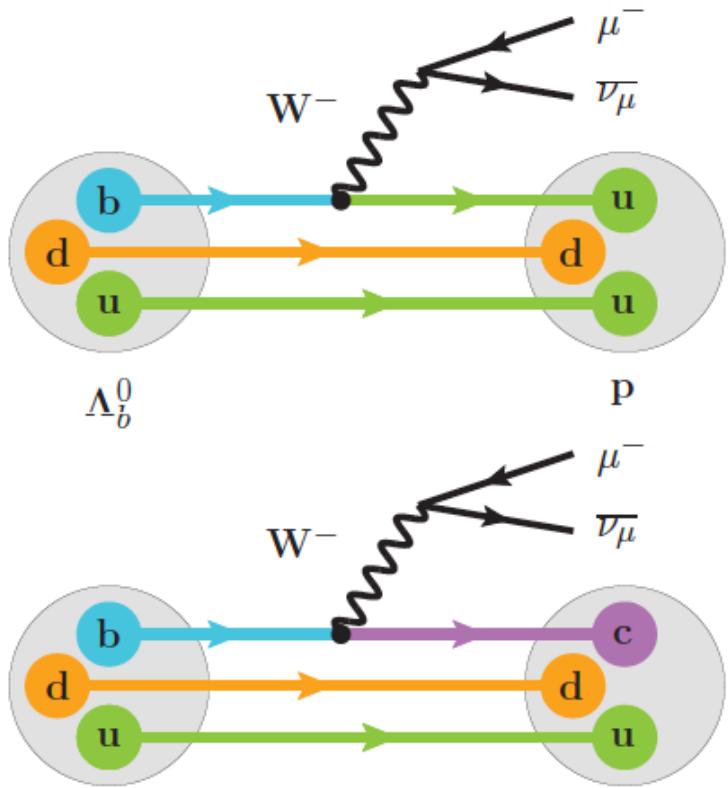
- Fermilab/MILC 2015 + BaBar + Belle  $B \rightarrow \pi/\nu$   
Fermilab/MILC 2008 + HFAG 2014,  $B \rightarrow \pi/\nu$   
RBC/UKQCD 2015 + BaBar + Belle,  $B \rightarrow \pi/\nu$   
Imsong *et al.* 2014 + BaBar12 + Belle13,  $B \rightarrow \pi/\nu$   
HPQCD 2006 + HFAG 2014,  $B \rightarrow \pi/\nu$   
I  
BLNP 2004 + HFAG 2014,  $B \rightarrow X_u/\nu$   
UTFit 2014, CKM unitarity

# Possible explanations

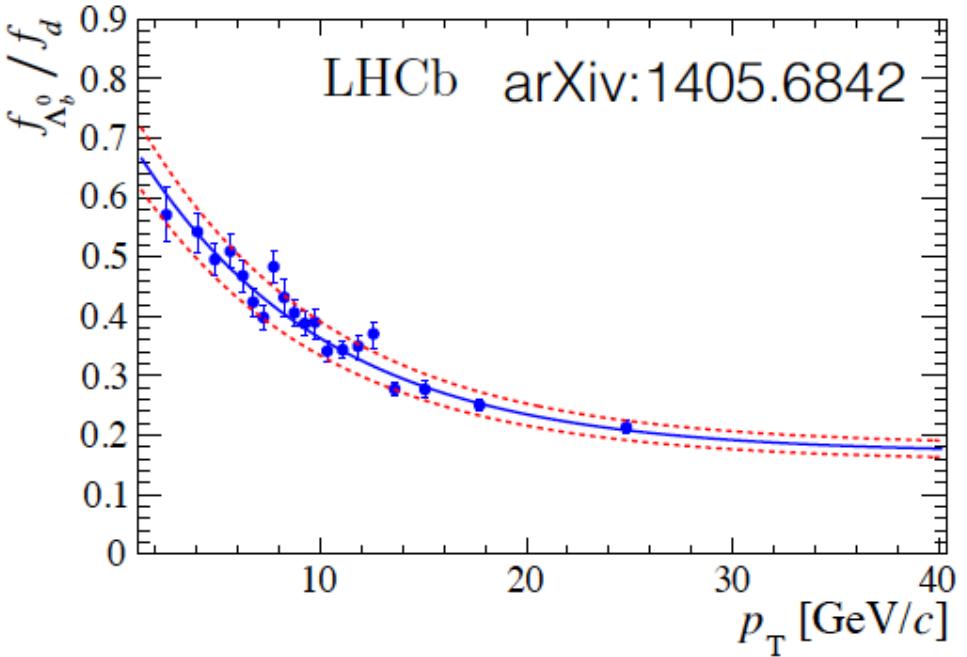


- Failure of LQCD & Sum rules to predicted exclusive form-factors?
- Failure of the HQE to evaluate correctly the hadronic matrix element?
  - General framework: non-quantified uncertainties such as assumption of quark-hadron duality
  - Analysis specific: effects of phase space cuts introduced to suppress Cabibbo favored semileptonic decay background
- Problems in Monte Carlo modeling the inclusive charmless semileptonic decays?
- New physics?  
⇒ **More measurements are needed!**

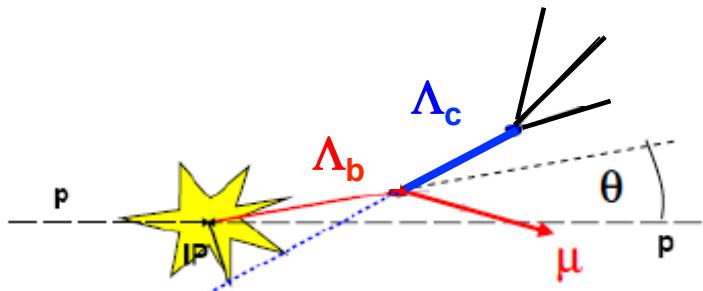
# Why $\Lambda_b$ semileptonic decays?



- ❑ Use of b-baryon decays provides complementary information to B mesons
- ❑ At LHCb  $\Lambda_b$  are produced copiously



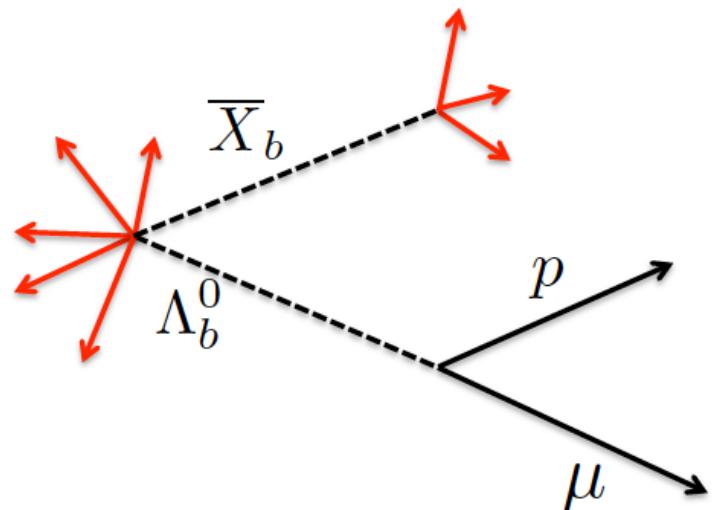
- 1) Kinematic constraints allow determination of magnitude of  $\Lambda_b$  momentum (modulo 2-fold ambiguity)
- 2) LHCb determines the ratio  $\Lambda_b \rightarrow p\mu\nu / \Lambda_b \rightarrow \Lambda_c\mu\nu$  in high  $q^2$  region
  - ⇒ Minimize background from Cabibbo favored decays in  $\Lambda_b \rightarrow p\mu\nu$
  - ⇒ Use region where lattice predictions are expected to be more reliable



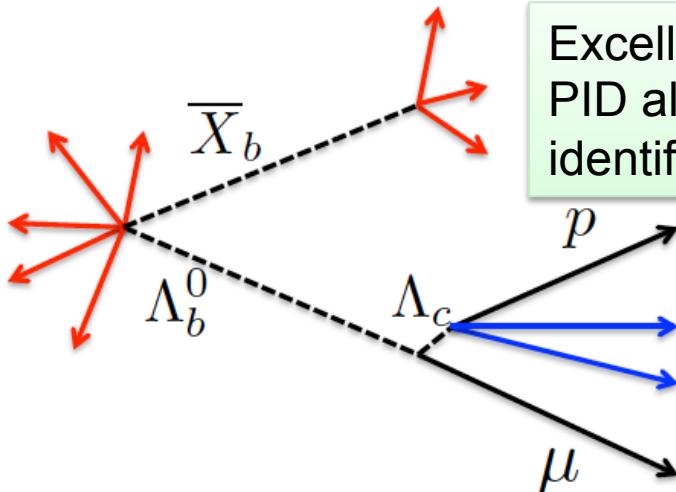
- 3) Use normalization factor derived from Lattice QCD calculation to extract  $|V_{ub}/V_{cb}|^2$

# The $\Lambda_b \rightarrow p\mu\nu$ signal at LHCb

Signal



Background



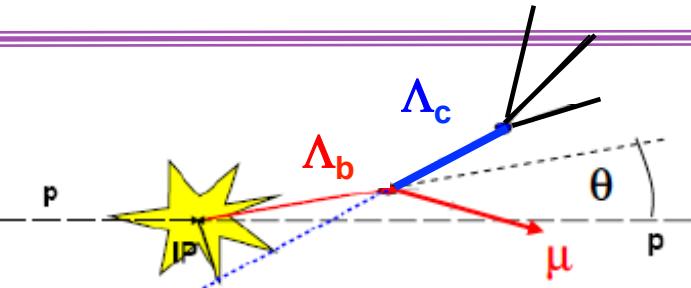
Cabibbo favored decays typically have additional tracks forming a good secondary vertex with the proton emitted in the semileptonic decay  $\Rightarrow$  train multivariate classifier to distinguish between these two configurations, get 90% rejection & 80% efficiency

# The corrected mass

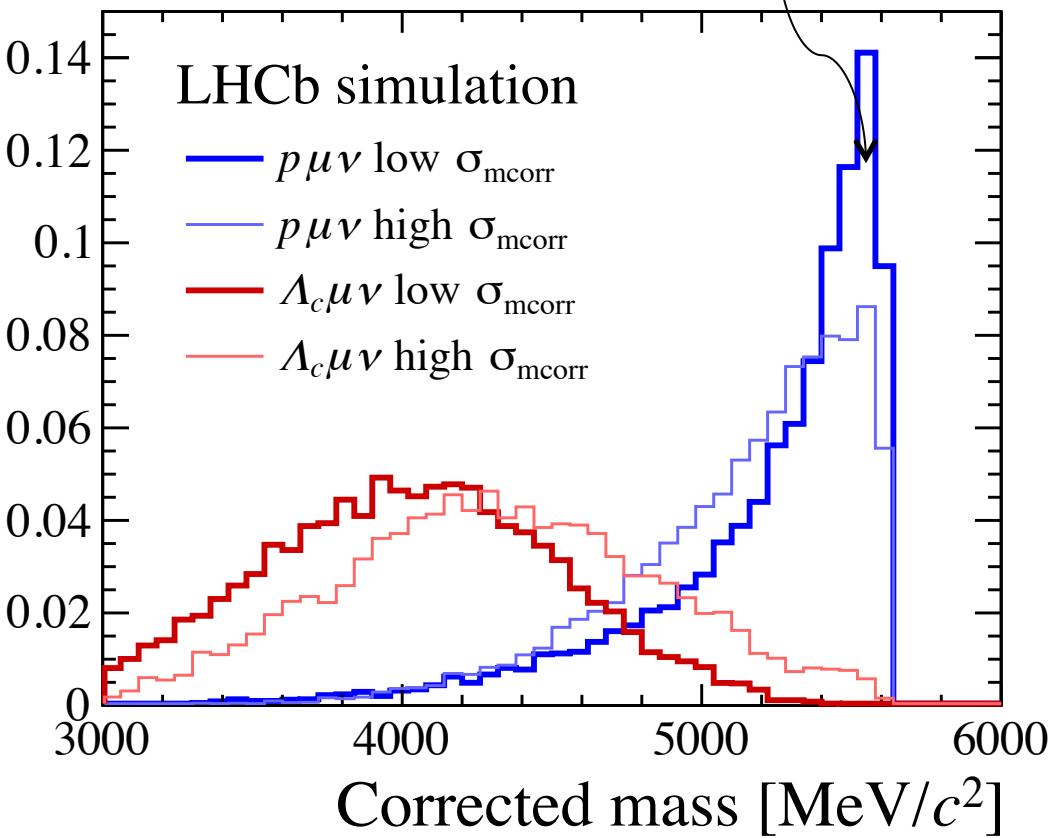
- Displaced vertex information allow to define the corrected mass

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

- $M_{corr}$  is used to disentangle different final state components
- Uncertainty in  $M_{corr}$  is used to discriminate between signal and background



$M_{corr}$  peaks at  $\Lambda_b$  mass also when  $\nu$  is there



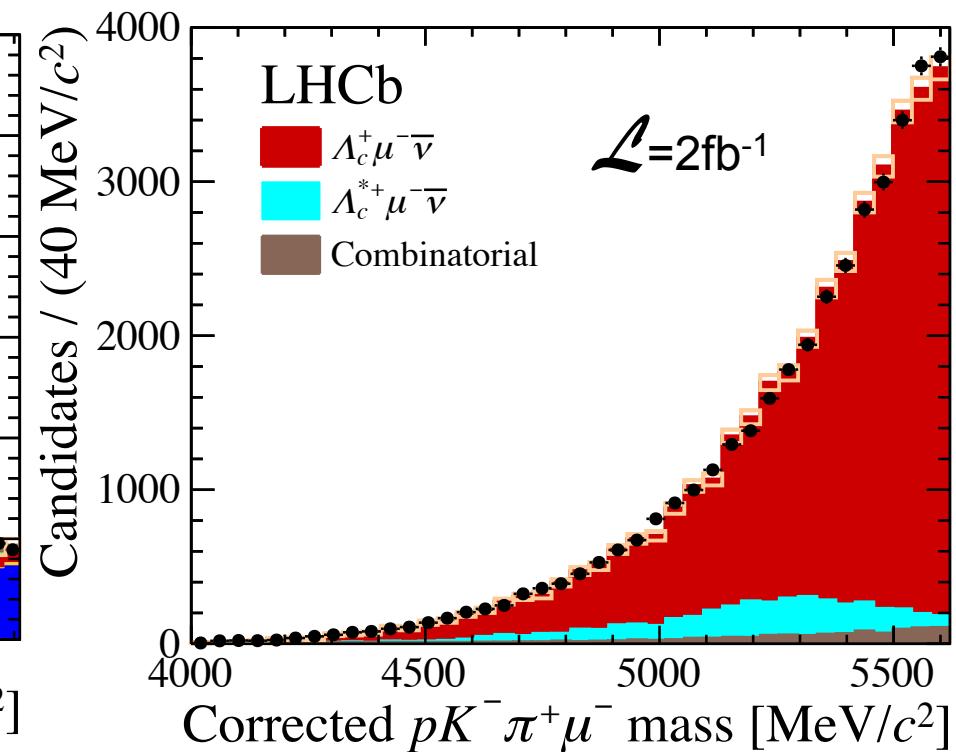
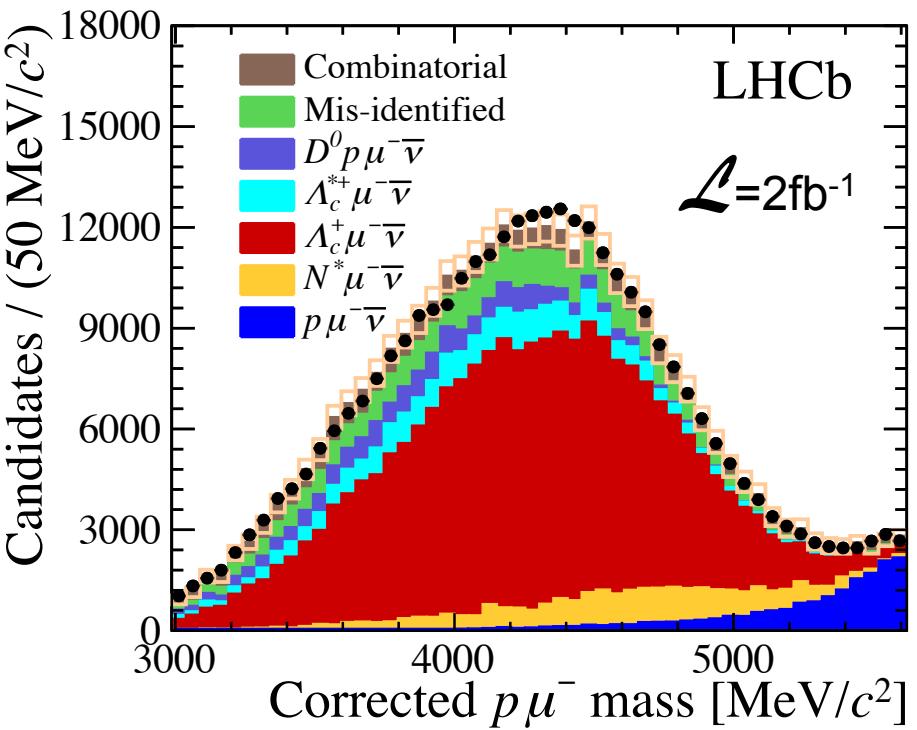
## The signal fits

arXiv:1504.01568



$$N(\Lambda_b \rightarrow p\mu\nu) = 17687 \pm 733$$

$$N(\Lambda_b \rightarrow \Lambda_c \mu\nu) = 34255 \pm 571$$



# Experimental result



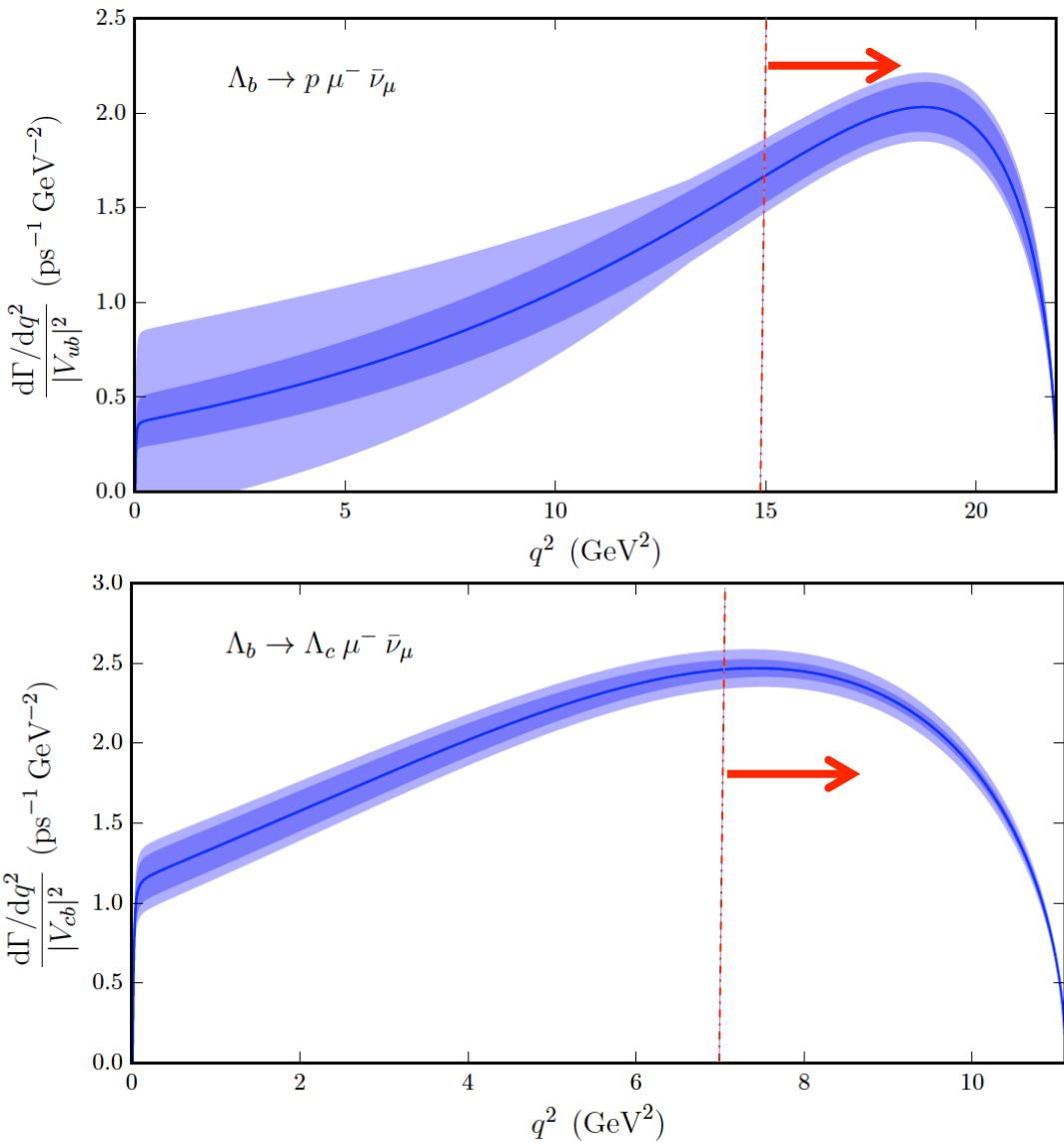
$$R_{\text{exp}} = \frac{B(\Lambda_b^0 \rightarrow p \mu^- \bar{\nu}_\mu) \Big|_{q^2 > 15 \text{ GeV}^2}}{B(\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu) \Big|_{q^2 > 7 \text{ GeV}^2}} = (1.0 \pm 0.04(\text{stat}) \pm 0.08(\text{syst})) \times 10^{-2}$$

arXiv:1504:01568

Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \rightarrow p K^+ \pi^-)$	+4.7 -5.3
Trigger	3.2
Tracking	3.0
$\Lambda_c^+$ selection efficiency	3.0
$\Lambda_b^0 \rightarrow N^* \mu^- \bar{\nu}_\mu$ shapes	2.3
$\Lambda_b^0$ lifetime	1.5
Isolation	1.0
Form factors	0.5
$\Lambda_b^0$ kinematics	0.5
$q^2$ migration	0.4
Particle Identification Efficiency	0.2
Total	+7.8 -8.2

# Theory input

arXiv:1503.01421v3  
Detmold,Lehner,Meinel



- Most recent calculation uses 2+1 flavors of dynamical domain-wall fermions, RBC & UKQCD configurations &  $q^2$  dependence parameterized with z-expansion
- LHCb uses  $q^2 > 15 \text{ GeV}^2$  for  $\Lambda_b \rightarrow p \mu \nu$  and  $q^2 > 7 \text{ GeV}^2$   $\Lambda_b \rightarrow \Lambda_c \mu \nu$   
⇒ Most reliable theory prediction

# Theory input II

## □ Theory normalization

arXiv:1503.01421v3

$$R_{TH} = \frac{\frac{1}{|V_{ub}|^2} \int_{15 GeV^2}^{q_{\max}^2} \frac{d\Gamma(\Lambda_b^0 \rightarrow p \mu \bar{\nu}_\mu)}{dq^2} dq^2}{\frac{1}{|V_{cb}|^2} \int_{7 GeV^2}^{q_{\max}^2} \frac{d\Gamma(\Lambda_b^0 \rightarrow \Lambda_c^0 \mu \bar{\nu}_\mu)}{dq^2} dq^2} = \frac{(12.31 \pm 0.76 \pm 0.77) ps^{-1}}{(8.37 \pm 0.16 \pm 0.34) ps^{-1}} = 1.471 \pm 0.094 \pm 0.109$$

4.9% theoretical error on  $|V_{ub}/V_{cb}|$

$$\frac{\Gamma(\Lambda_b^0 \rightarrow p \mu \bar{\nu}_\mu)}{|V_{ub}|^2} = (25.7 \pm 2.6 \pm 4.6) ps^{-1}$$

$$\frac{\Gamma(\Lambda_b^0 \rightarrow \Lambda_c^+ \mu \bar{\nu}_\mu)}{|V_{cb}|^2} = (21.5 \pm 0.8 \pm 1.1) ps^{-1}$$

Using the full  $\Gamma_c$  width, theoretical error on  $|V_{cb}|$  3.2%, using  $\Gamma_c$  in  $q^2 \geq 7 GeV^2$  region, theoretical error 2.2%

Using:

$$V_{ub} = V_{cb}^{excl} \sqrt{R_{\text{exp}} / R_{\text{TH}}} = V_{cb}^{excl} \sqrt{\frac{(1.0 \pm 0.04 \pm 0.08) \times 10^{-2}}{1.471 \pm 0.095 \pm 0.110}}$$

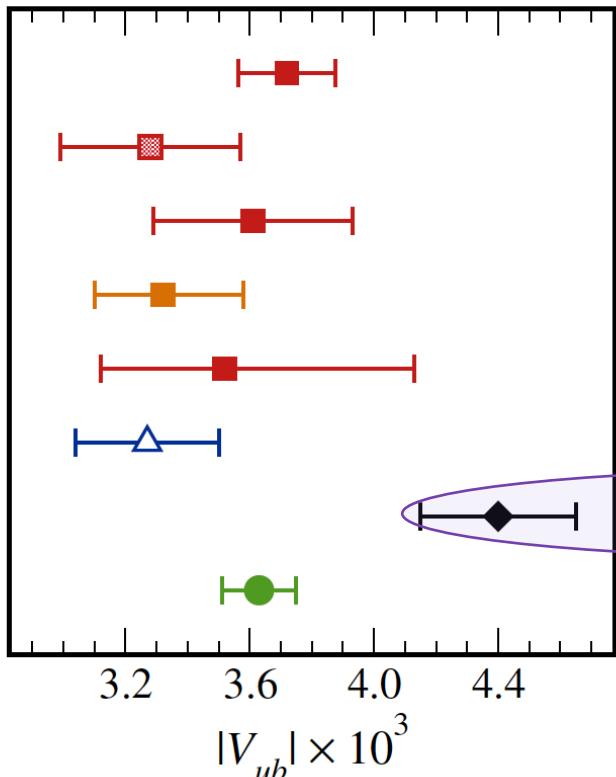
and

$$|V_{cb}^{excl}| = (39.5 \pm 0.8) \times 10^{-3}$$

PDG2014

LHCb gets:  $|V_{ub}| = (3.27 \pm \underbrace{0.15}_{\text{exp}} \pm \underbrace{0.16}_{\text{lattice}} \pm \underbrace{0.06}_{V_{cb} \text{ norm.}}) \times 10^{-3}$

# $|V_{ub}|$ current status



arXiv:1503.07839

Fermilab/MILC 2008 + HFAG 2014,  $B \rightarrow \pi l \nu$

RBC/UKQCD 2015 + BaBar + Belle,  $B \rightarrow \pi l \nu$

Imsong *et al.* 2014 + BaBar12 + Belle13,  $B \rightarrow \pi l \nu$

HPQCD 2006 + HFAG 2014,  $B \rightarrow \pi l \nu$

Detmold *et al.* 2015 + LHCb 2015,  $\Lambda_b \rightarrow p l \nu$

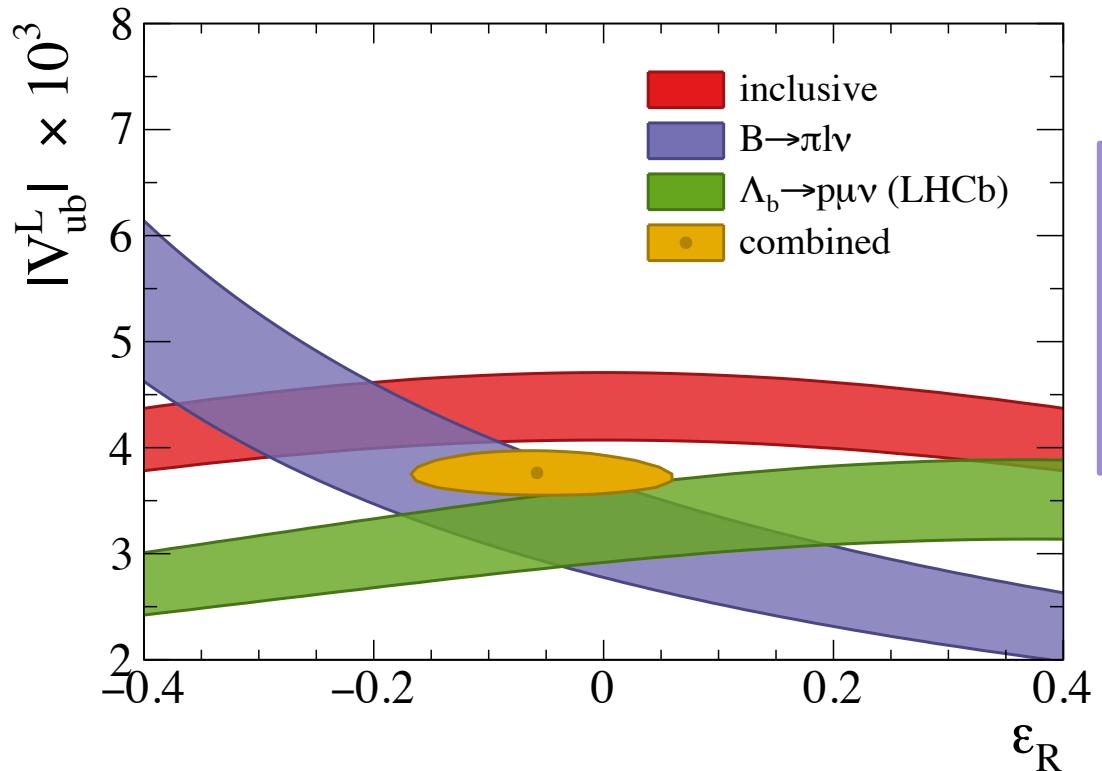
BLNP 2004 + HFAG 2014,  $B \rightarrow X_u l \nu$  ← inclusive

UTFit 2014, CKM unitarity

- ❑ Exclusive data consistent with each other and with indirect determination of  $|V_{ub}|$
- ❑ New physics in  $|V_{ub}|$  from inclusive measurement?

# New physics?

Conjecture that discrepancy between  $|V_{ub}|$  from inclusive and exclusive determinations could be attributed to right-handed currents.



arXiv:0907.2461  
arXiv:1033.4022 ( $V_{cb}$ )  
arXiv:1408.2516v1

Constraint from this measurement disfavors this solution of the puzzle

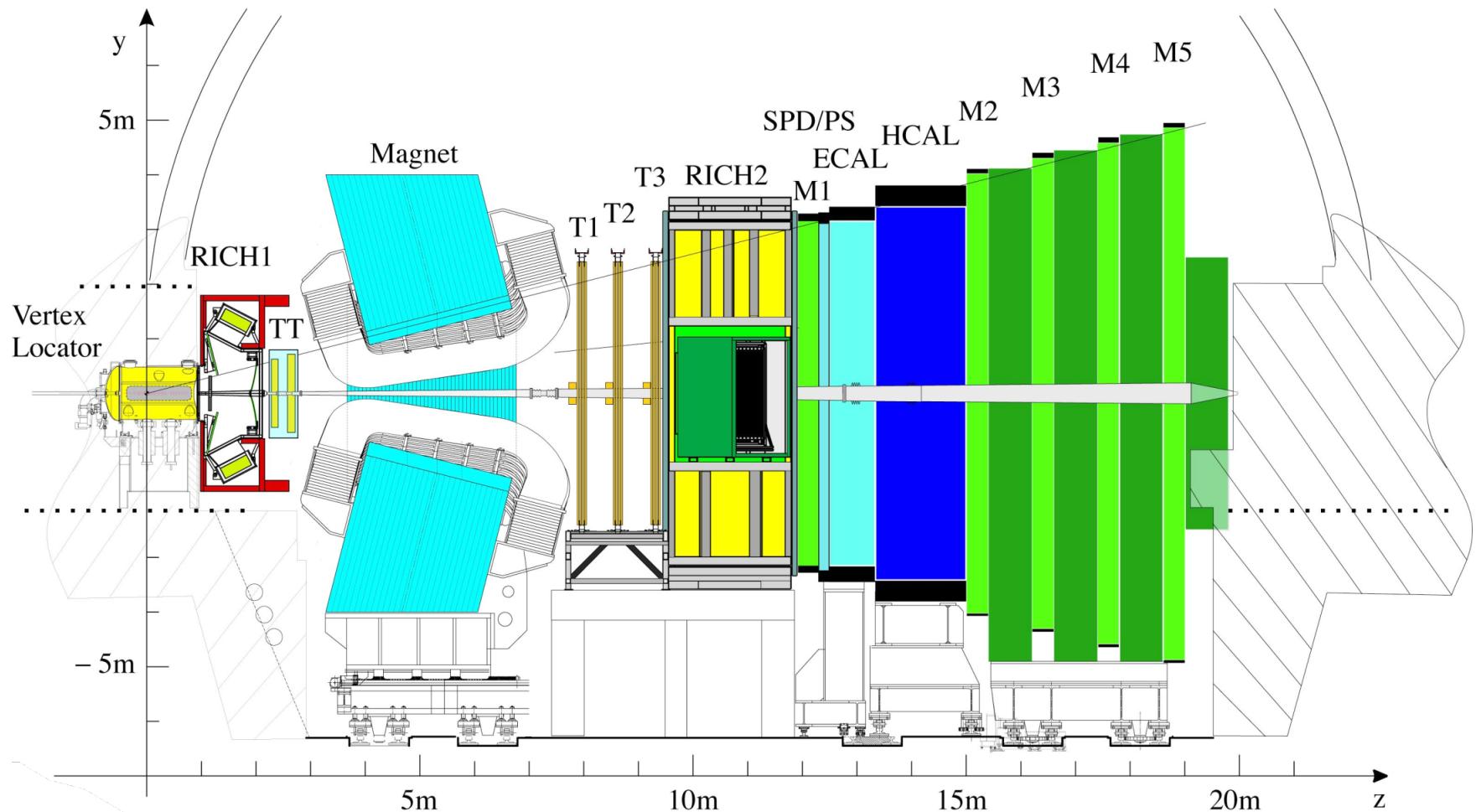
# Conclusions and outlook



- LHCb has performed its first high precision determination of  $|V_{ub}|$  and is poised to continue studies on  $V_{xb}$  from exclusive semileptonic decays:
  - Form factors and  $V_{cb}$  determination from  $\Lambda_b \rightarrow \Lambda_c \mu \nu$
  - New  $b \rightarrow u$  decays (e.g.  $B_s \rightarrow K \mu \nu$ )
  - ...
- Inclusive measurements with less restrictive phase space cuts may reduce tension on  $V_{ub}$  + refinement of previous exclusive studies (Belle II)
- New lattice QCD calculations on the way
- The pursuit of the ultimate precision on  $V_{xb}$  will keep us busy for a while!

# THE END

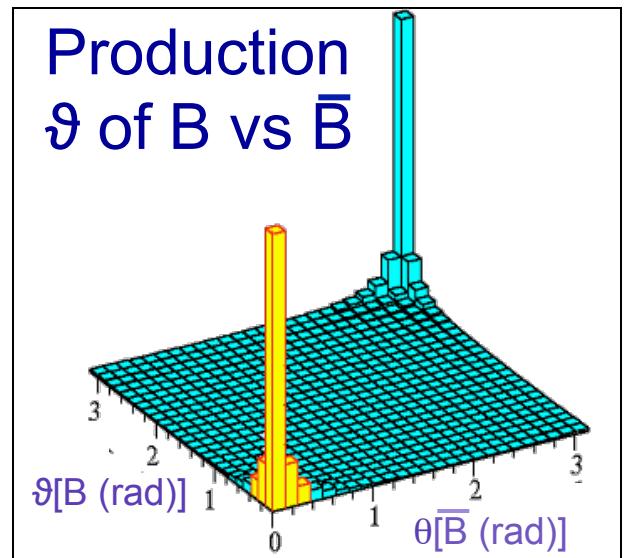
# The LHCb detector



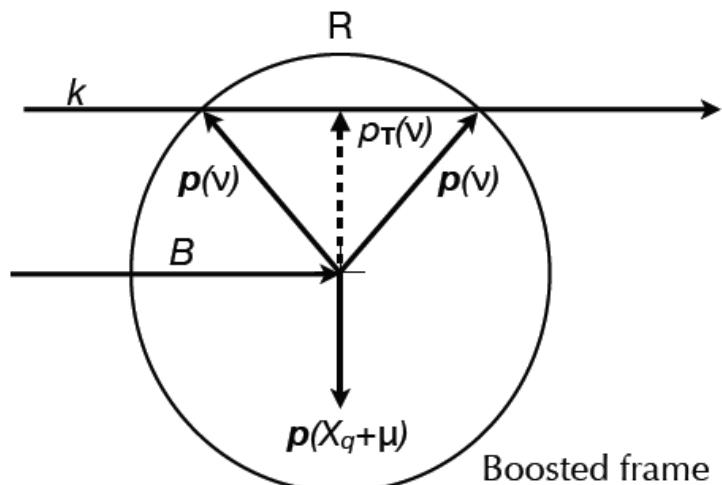
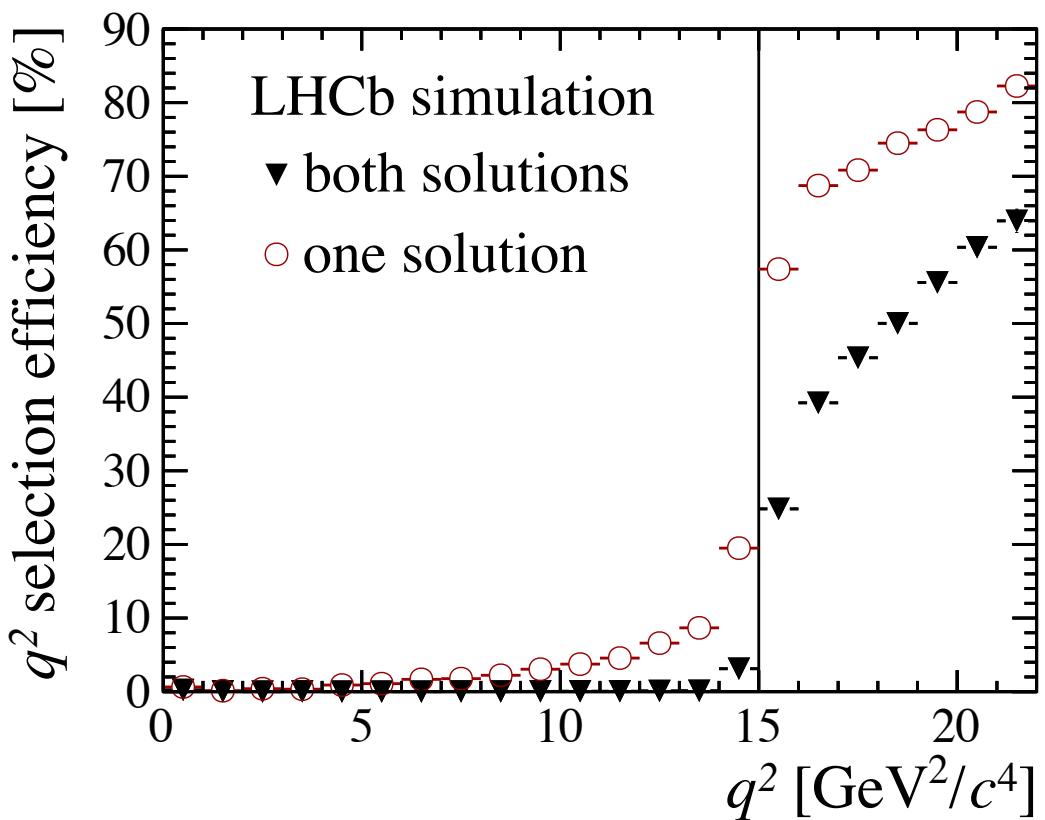
# The Forward Direction at the LHC

- In the forward region at LHC the  $b\bar{b}$  production  $\sigma$  is large
- The hadrons containing the  $b$  &  $\bar{b}$  quarks are both likely to be in the acceptance. Essential for “flavor tagging”
- LHCb uses the forward direction where the  $B$ 's are moving with considerable momentum  $\sim 100$  GeV, thus minimizing multiple scattering
- At  $\mathcal{L}=4 \times 10^{32} / \text{cm}^2/\text{s}$ , we get  $\sim 10^{12}$   $B$  hadrons in  $10^7$  sec in the LHCb acceptance.

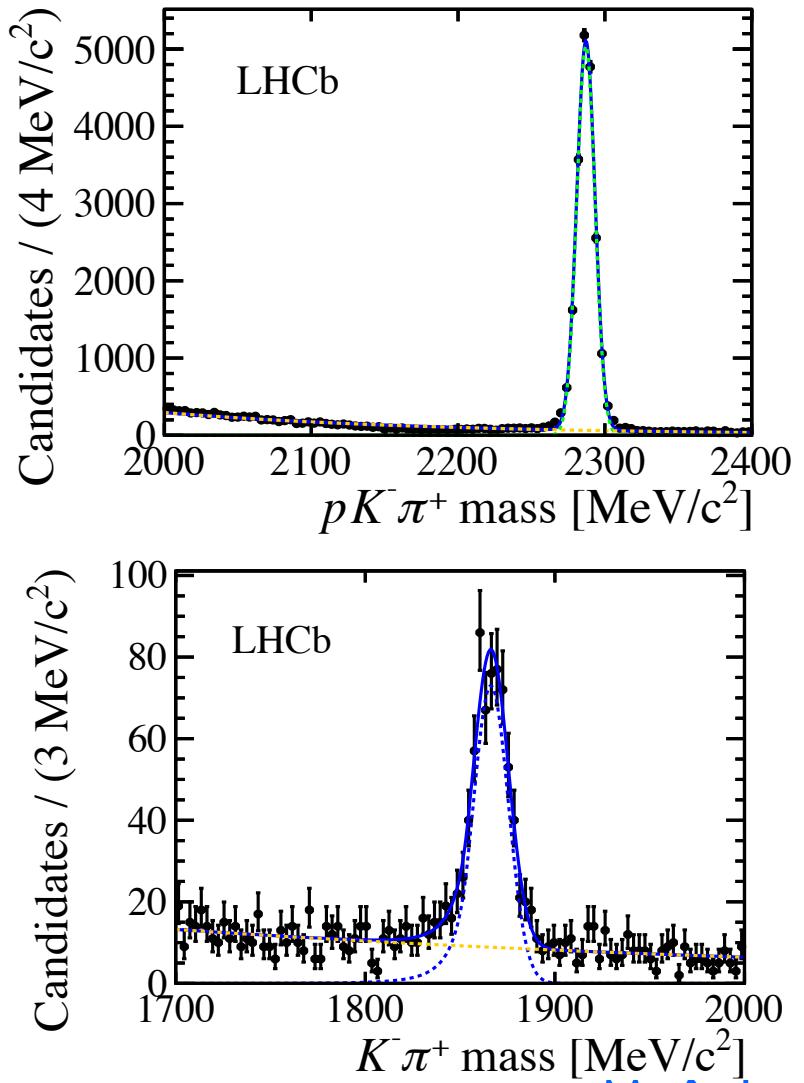
Measured cross section at 7 TeV in LHCb acceptance is  $\sim 90 \mu\text{b}$



# The two-fold ambiguity



# Experimental background studies



- After selection reconstruct additional tracks to determine background yields

