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$|V_{ub}|$: Experimental issues at LHCb

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Challenges in semileptonic B decays
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$|V_{ub}|$ is a challenge at a hadron machine

Measurement of V_{ub} was not part of the technical proposal of LHCb

We didn't think that we could do it

Other didn't think that we could do it neither

“It is particularly important to stress that many of the measurements that constitute the primary physics motivation for Super$B$ cannot be performed in the hadronic environment. For example, modes with missing energy, such as $B^+ \to \ell^+ \nu_\ell$ and $B^+ \to K^+ \nu \bar{\nu}$, measurements of the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$, and inclusive analyses of processes such as $b \to s\gamma$ are unique to Super$B$.”

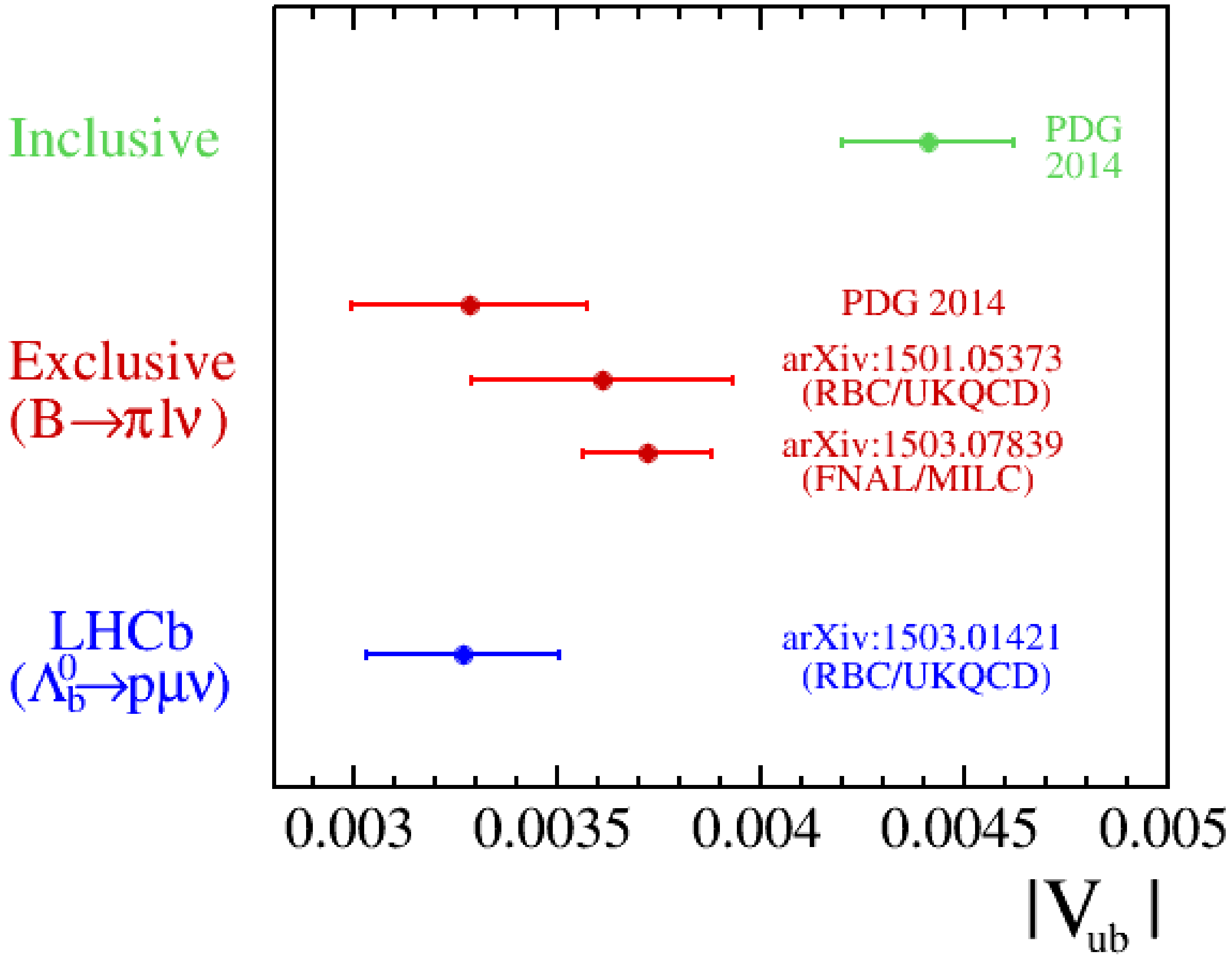
CDR, SuperB factory, arXiv 0709.0451

Will go through a few of the key developments that made it possible

Overview of recent LHCb measurement

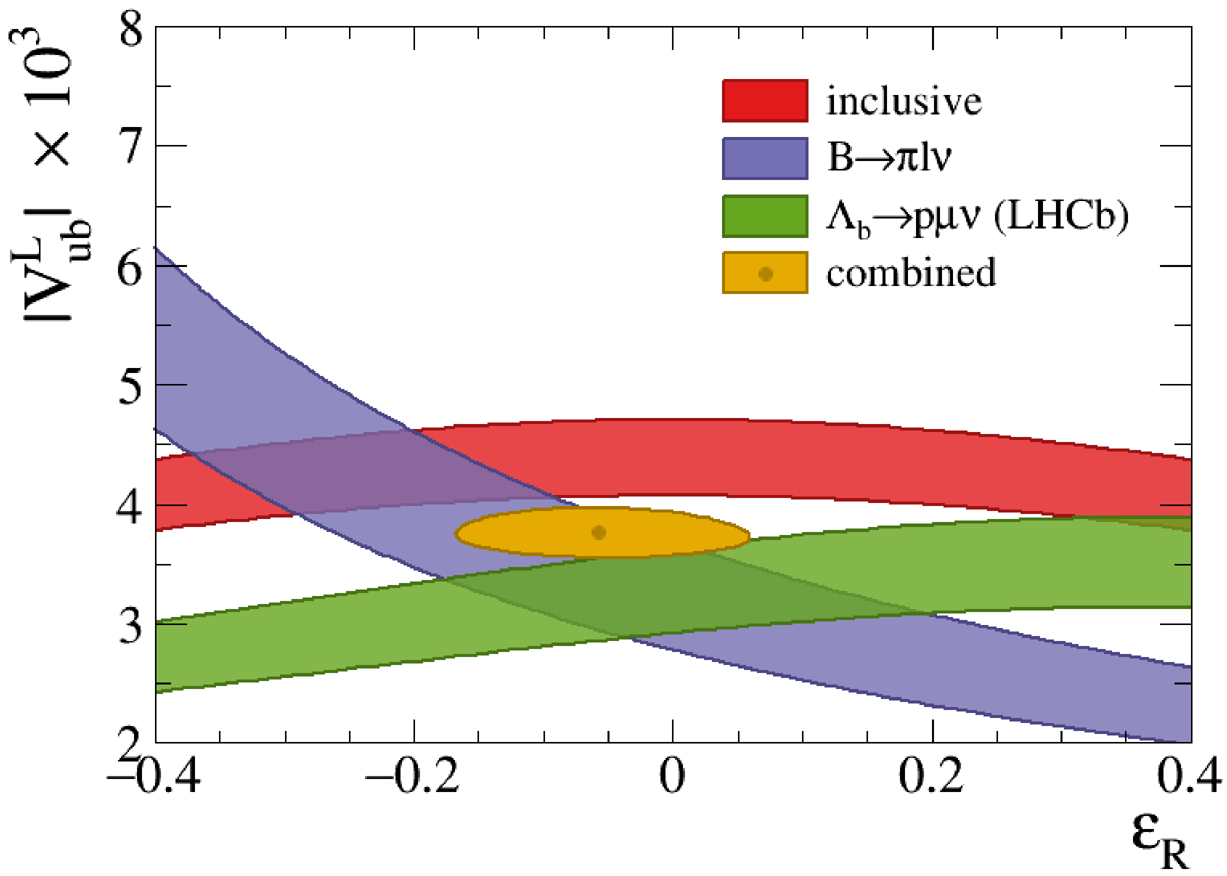
- Use the final state $\Lambda_b \rightarrow p\mu\upsilon$ for a $b\rightarrow u$ transition
  - First observation of this decay
- Normalise to the $\Lambda_b \rightarrow \Lambda_c(\rightarrow pK\pi)\mu\upsilon$ $b\rightarrow c$ transition
- Convert from ratio of yields to $|V_{ub}|/|V_{cb}|$
  - Use kinematic region where LQCD calculations are the most accurate
- Use PDG exclusive average of $|V_{cb}|$ to make measurement $|V_{ub}|=(3.27\pm015\pm0.17\pm0.06) \times 10^{-3}$
  - Uncertainties are experiment, lattice, $|V_{cb}|$
- Submitted to Nature Physics, arXiv:1504.01568

Comparing to other measurements

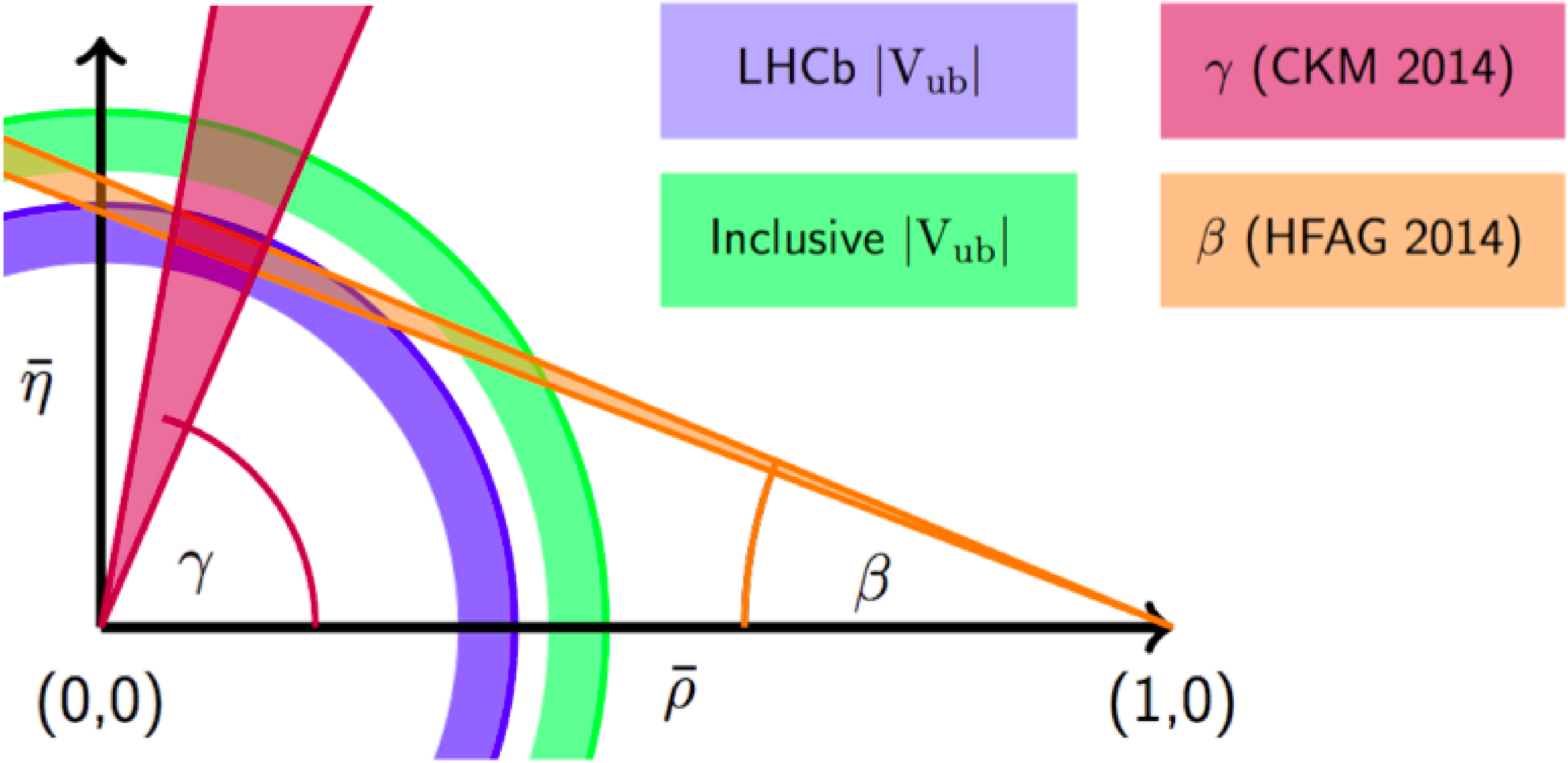


Right handed current

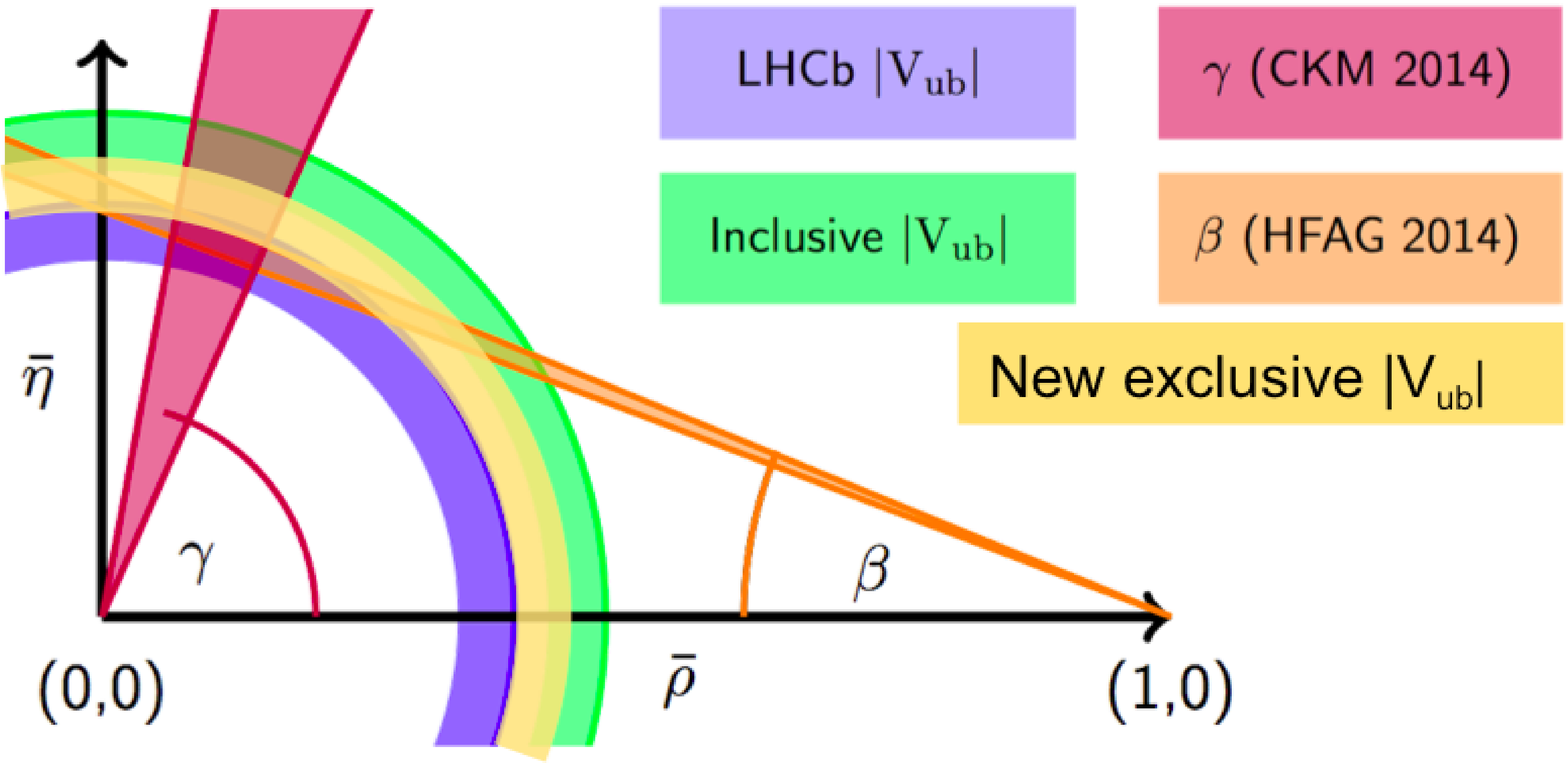
The dependence on a right handed current is different for $\Lambda_b \rightarrow p\mu\nu$ as there is also an axial vector current



Implication for unitarity test



Implication for unitarity test



What made $|V_{ub}|$ possible @ LHCb

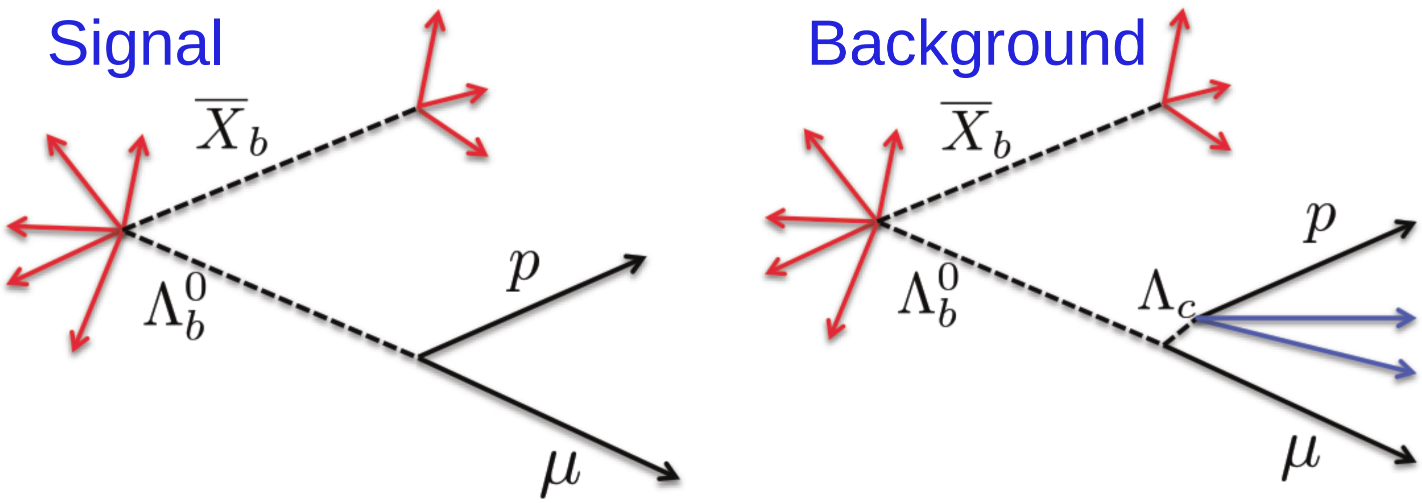
Use of baryon final state

- Approximately 20% of all b-hadrons produced at LHC are Λ_b baryons
  - $\Lambda_b \to p\mu\upsilon$ is thus viable, branching fraction is huge compared to many other LHCb decays
  - Amount of protons in decay products of b-hadrons much smaller than pions, thus much smaller combinatorial background than $B^+ \to \pi\mu\upsilon$
- BF($\Lambda_c(\to pK\pi)$) for normalisation now has 5% uncertainty
  - Belle measurement Phys. Rev. Lett. 113 (2014) 042002
- $\Lambda_b \to p$ form factors calculated in LQCD
  - W. Detmold, C. Lehner, and S. Meinel, arXiv:1503.01421
  - Gives 5% uncertainty on $|V_{ub}|$

Isolation

We can exploit that the signal $\Lambda_b \to p\mu\upsilon$ has no other tracks sharing secondary vertex

- While many of the $\Lambda_b \to \Lambda_c\mu\upsilon$ related background do



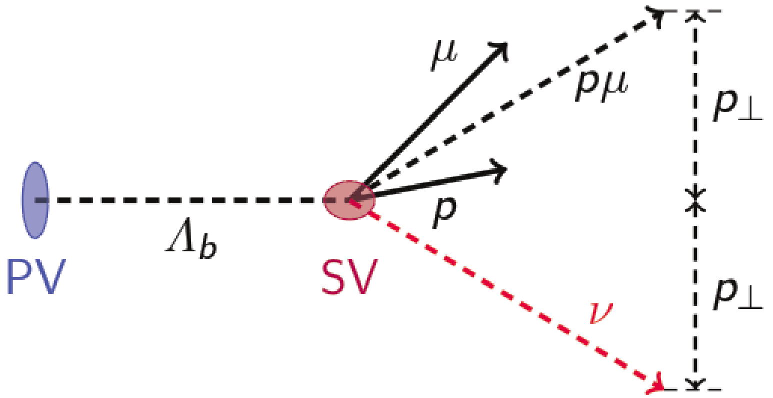
Train a boosted decision tree to separate the two categories

The corrected mass

No constraint from beam energy at a hadron machine

But flight vector between primary collision point and secondary decay point gives a different constraint

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

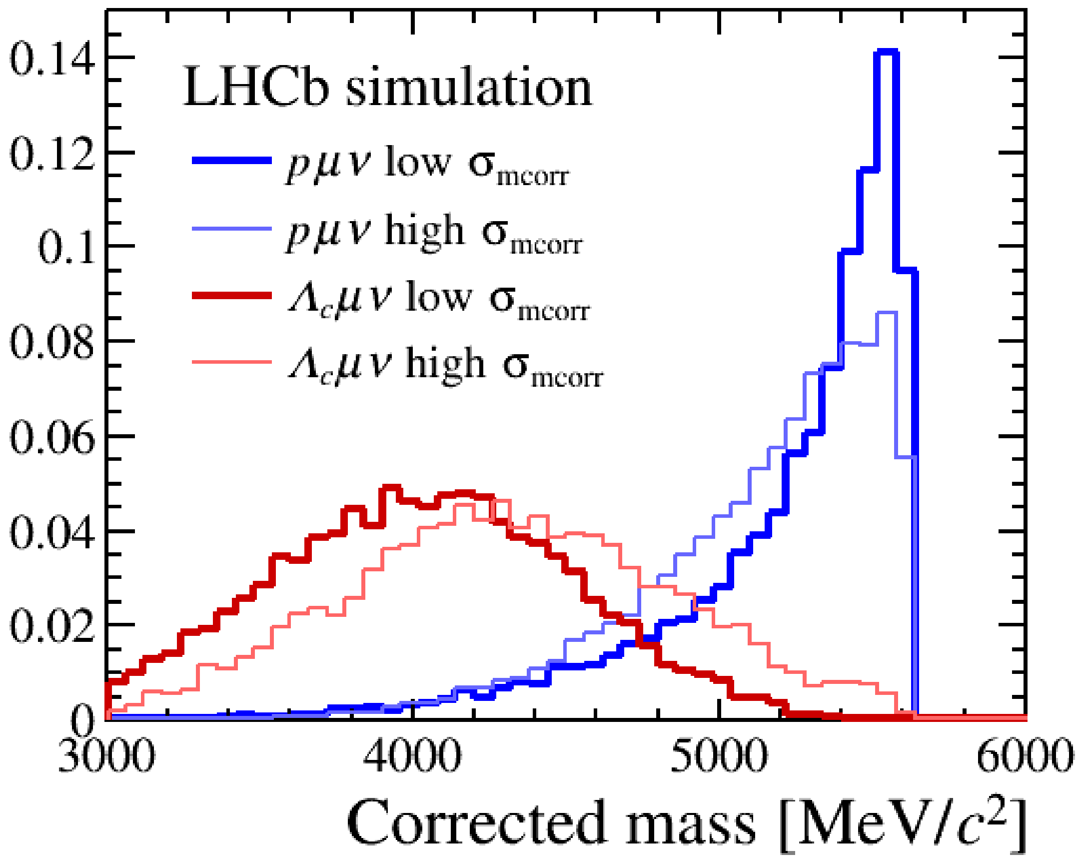


The corrected mass peaks at Λ_b mass when zero mass object is lost but has long tail to lower values

Very powerful to propagate **uncertainty** on corrected mass

The corrected mass

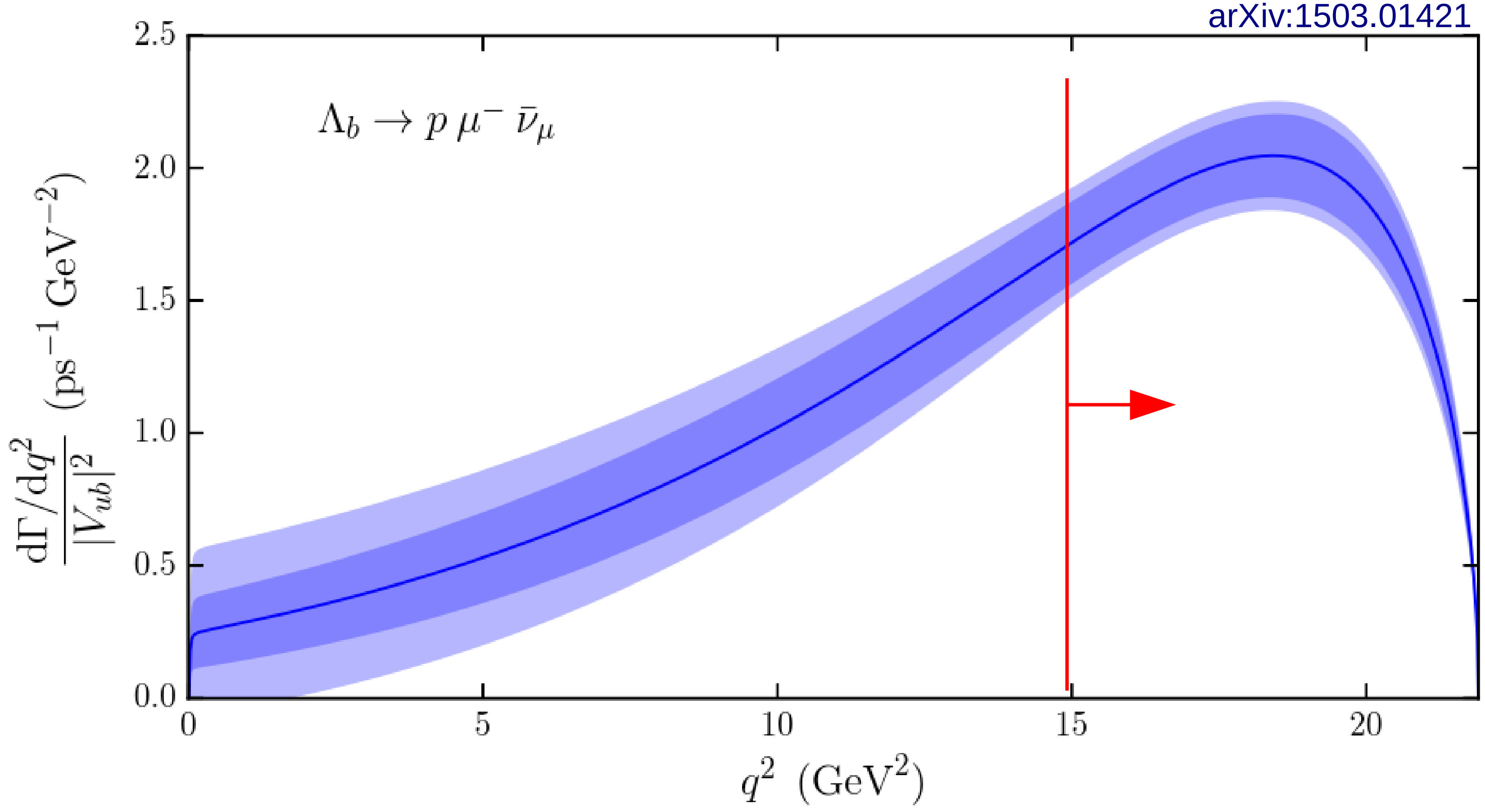
Separation between $\Lambda_b \rightarrow p\mu\upsilon$ signal and $\Lambda_b \rightarrow \Lambda_c\mu\upsilon$ related backgrounds improves when requiring low uncertainty on corrected mass



Reduced low q^2 dependence

- The LQCD calculation is most accurate at high q^2
  - A cut at 15 GeV^2 (7 GeV^2) is good for $\Lambda_b \to p\mu\upsilon$ ($\Lambda_b \to \Lambda_c\mu\upsilon$)

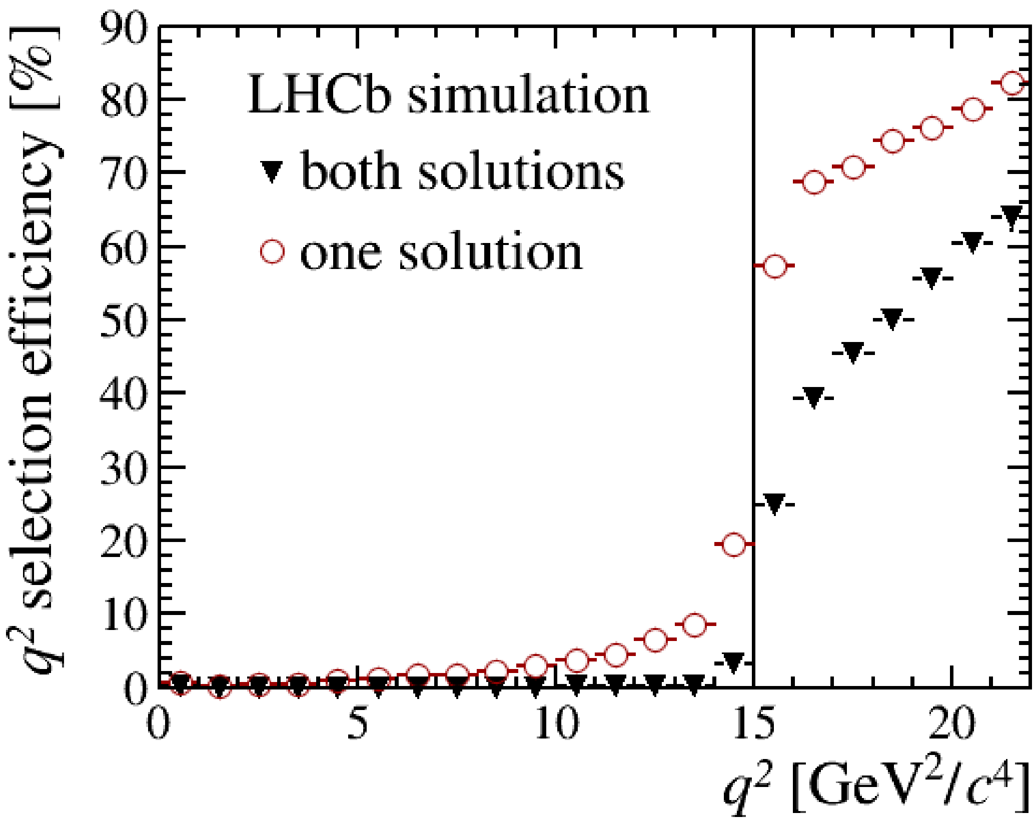
arXiv:1503.01421



Reduced low q^2 dependence

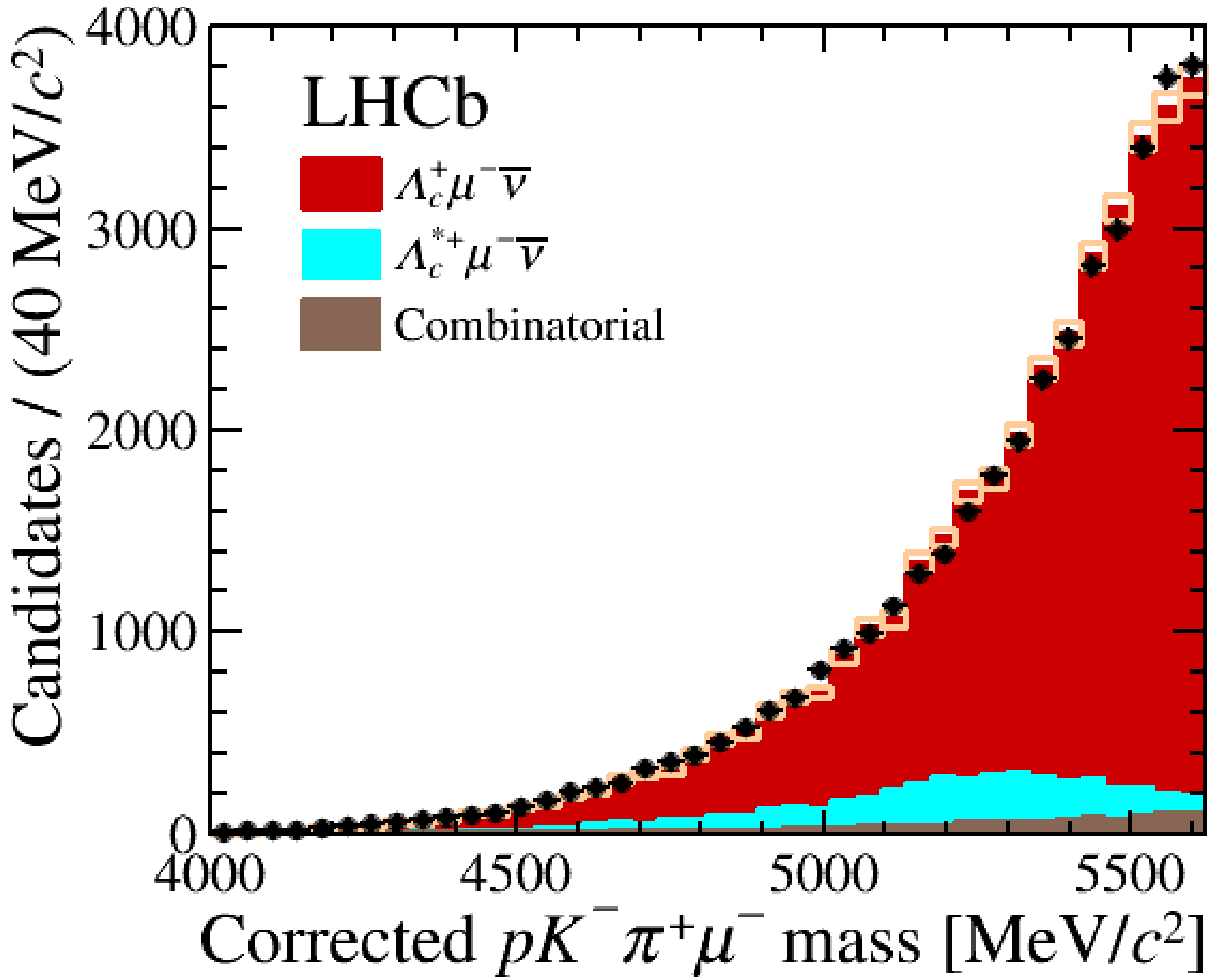
Missing neutrino means that there is 2-fold ambiguity for q^2

- Requiring **both** solutions to be above 15 GeV^2 reduce contribution from below 15 GeV^2 to tiny resolution effect



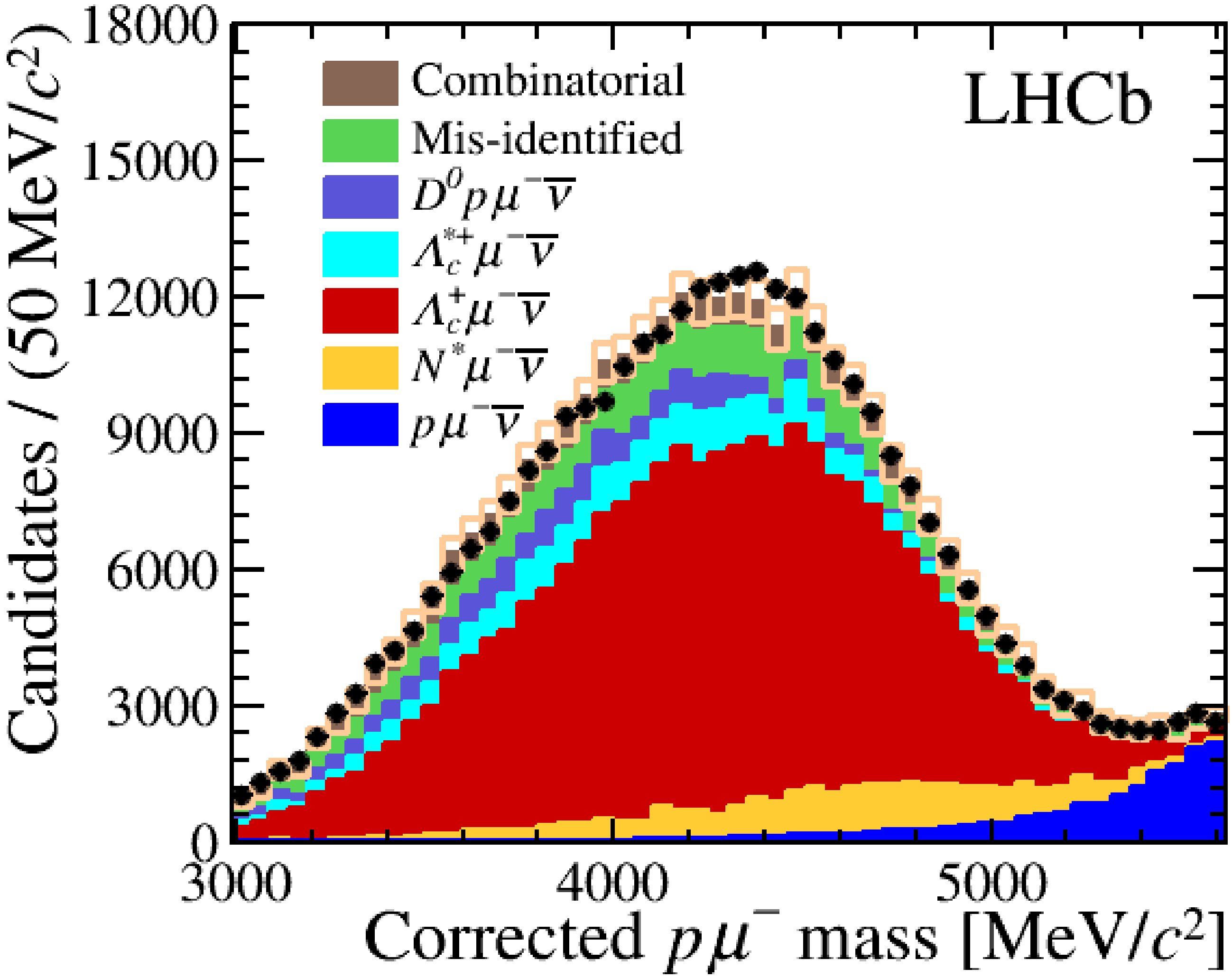
Normalisation mode

$\Lambda_b \rightarrow \Lambda_c(\rightarrow pK\pi)\mu\upsilon$



Signal mode

$\Lambda_b \rightarrow p\mu\upsilon$



Systematics of measurement

Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	${}^{+4.7}_{-5.3}$
Trigger	3.2
Tracking	3.0
Λ_c^+ selection efficiency	3.0
$\Lambda_b^0 \to N^*\mu^-\overline{\nu}_\mu$ shapes	2.3
Λ_b^0 lifetime	1.5
Isolation	1.4
Form factor	1.0
Λ_b^0 kinematics	0.5
q^2 migration	0.4
PID	0.2
Total	${}^{+7.8}_{-8.2}$

Other possible measurements

$\Lambda_b \rightarrow p\mu\upsilon$ differential spectra

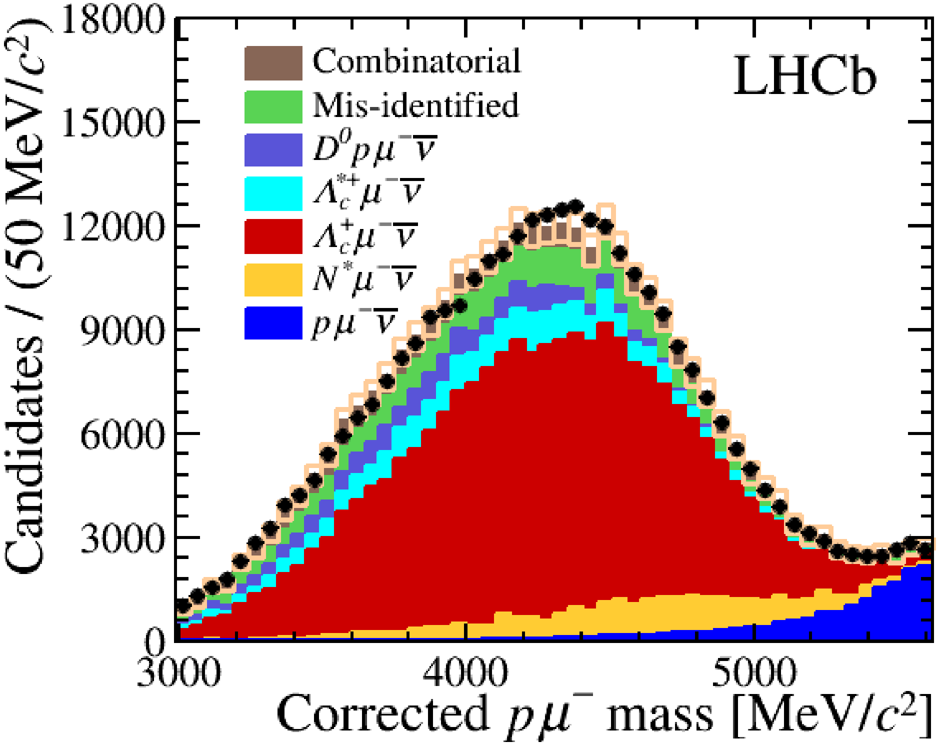
- Is there an interest in measuring the differential spectra of $\Lambda_b \rightarrow p\mu\upsilon$?
  - For branching fraction measurement independent of z-parametrisation?
- It is not a trivial measurement
  - The trick of selecting both q^2 solutions to be above some threshold would have to be modified
    - Resolution on correct solution is about 1 GeV^2, on the wrong one about 4 GeV^2
  - Signal yield will be much lower at low q^2
    - Not directly a problem but will make combinatorial background more of an issue
  - Proton and muon will point back towards primary vertex at low q^2 giving a potential new background source

Explicit measurement of $\Lambda_b \to N^*\mu\upsilon$ states

We could try to measure $\Lambda_b \to N^*\mu\upsilon$ directly

- Would need to look for $N^* \to p\pi^+\pi^-$ final state

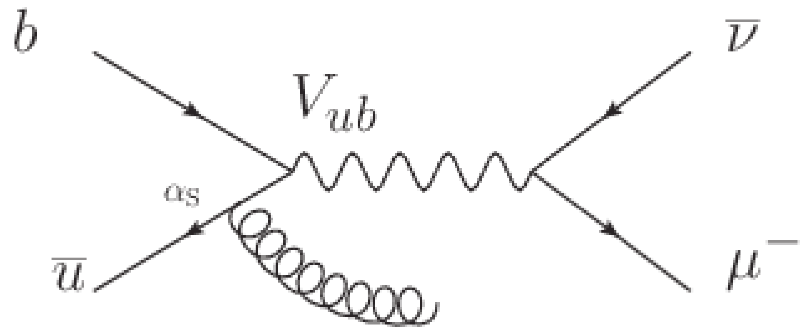
Could be used to reduce the uncertainty on the N* states that are included with Gaussian constraints (at the 100% level on BF) in current fit



B → μυ with a twist

To find B → μυ looks imposible at LHCb

But maybe we can do something similar



No helicity suppression and leads to final state

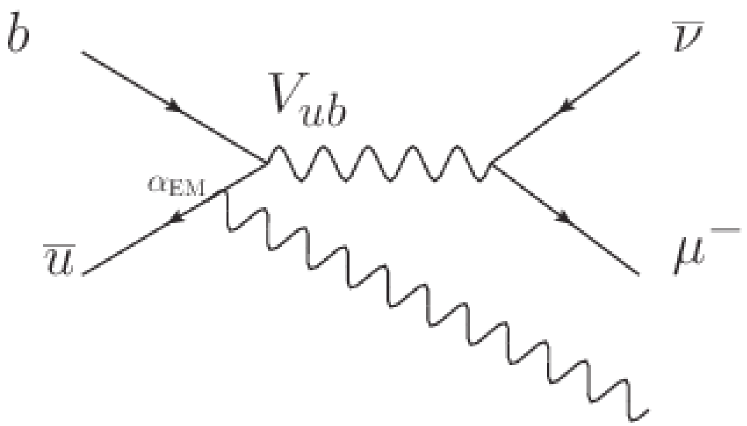
- $B^+ \to \mu\upsilon\varphi$ from gluon
- … but φ couples to light quarks so also a tree level diagram

Any BF prediction?

Might be more interesting as general $B^+ \to \mu\upsilon K^+K^-$ as input to $|V_{ub}|$ inclusive measurement

B → μυ with a twist

Another option is to have a hard initial state photon



Also no helicity suppression and leads to final states

- B → μυγ (hard/impossible at LHCb)
- B → μυμμ from virtual photon (very clean signature)

Are these decays interesting?

- Obviously not directly comparable to B^+ → τυ

Any BF predictions?

$B \to p\bar{p}\mu\upsilon$

- The decay has a very clean signature in LHCb with two protons
  - Belle has evidence for this decay,
    - $BF = (5.8^{+2.6}_{-2.3}) \times 10^{-6}$
- Potential for an angular analysis if yield is much higher in LHCb
  - Similar to studies of $B^0 \to \rho^0\mu\upsilon$ and $B^0_s \to K^{*+}\mu\upsilon$?
  - Is the lack of light $p\bar{p}$ resonances between threshold and J/ψ an advantage or a disadvantage?

Inclusive $|V_{ub}|$?

- It might be possible in LHCb to measure the inclusive rate $B_c^+ \rightarrow X_c \mu \upsilon$
  - Would take advantage of that all X_c will go through either of D^0, D^+, D_s^+ and Λ_c^+ weak decays
- Normalisation would be an issue as B_c^+ production has large uncertainty.
  - Could normalise to $B_c^+ \rightarrow J/\psi\ \mu \upsilon$ but this might defeat the purpose of doing something in an inclusive way
  - O maybe look at nearly inclusive $|V_{cb}|$ from $B_c \rightarrow J/\psi\ X\ \mu \upsilon$ and $B_c \rightarrow D D_{(s)} X \mu \upsilon$
- Any other use of B_c^+ semileptonic decays?

V_{ub} transitions with a τ

- Should we look for b→u transitions with a τ?
  - Could we see a huge effect there?
- If there is something new in B→D*τυ ...
  - and it does not follow CKM structure …
  - the relative effect in B→πτυ and Λ_b→pτυ may be much bigger compared to the SM contribution??

Conclusion

The first semileptonic $b \rightarrow u$ decay has been measured at LHCb

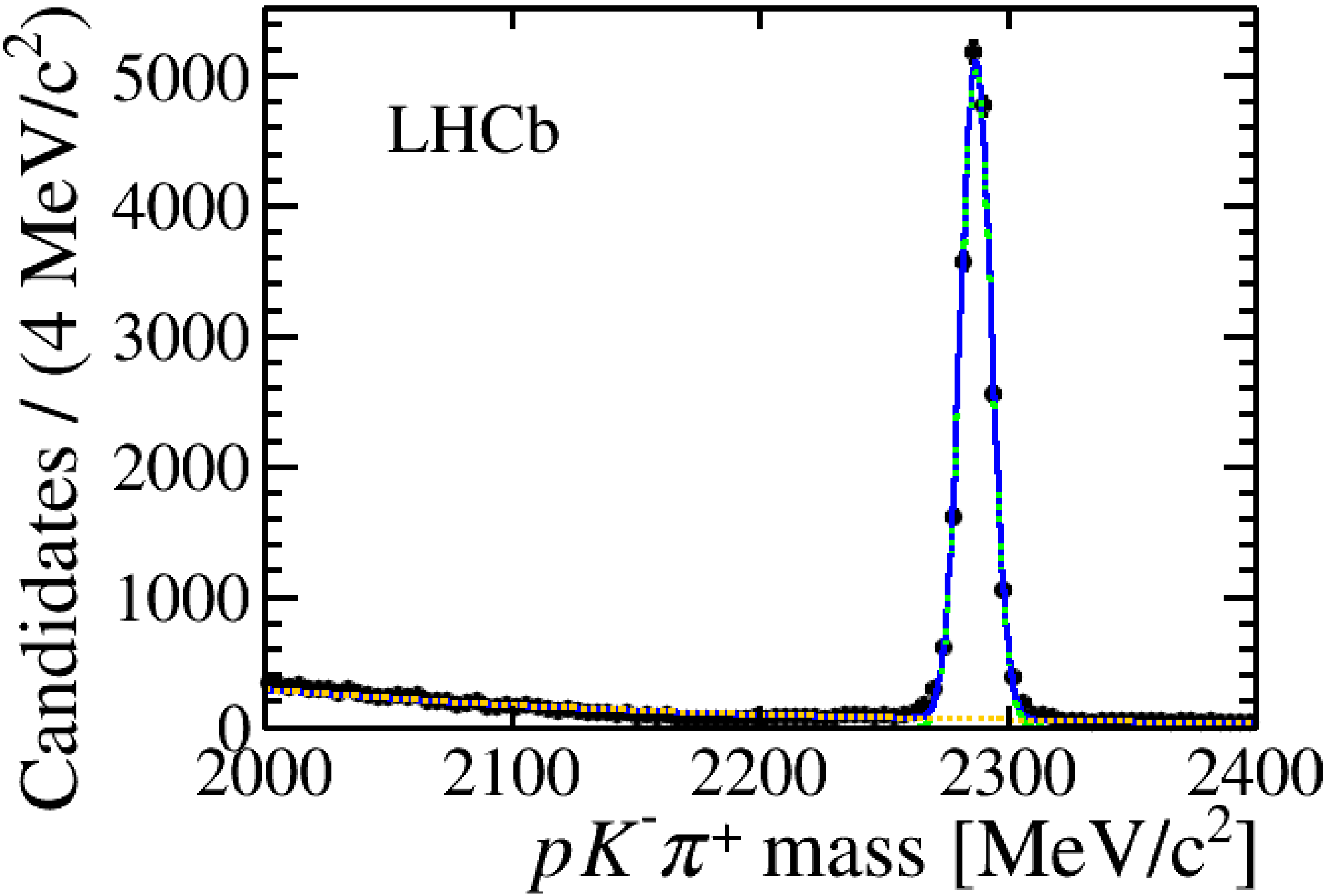
Many other measurements look experimentally promising

- Some theoretical input is required on which measurements are the most important

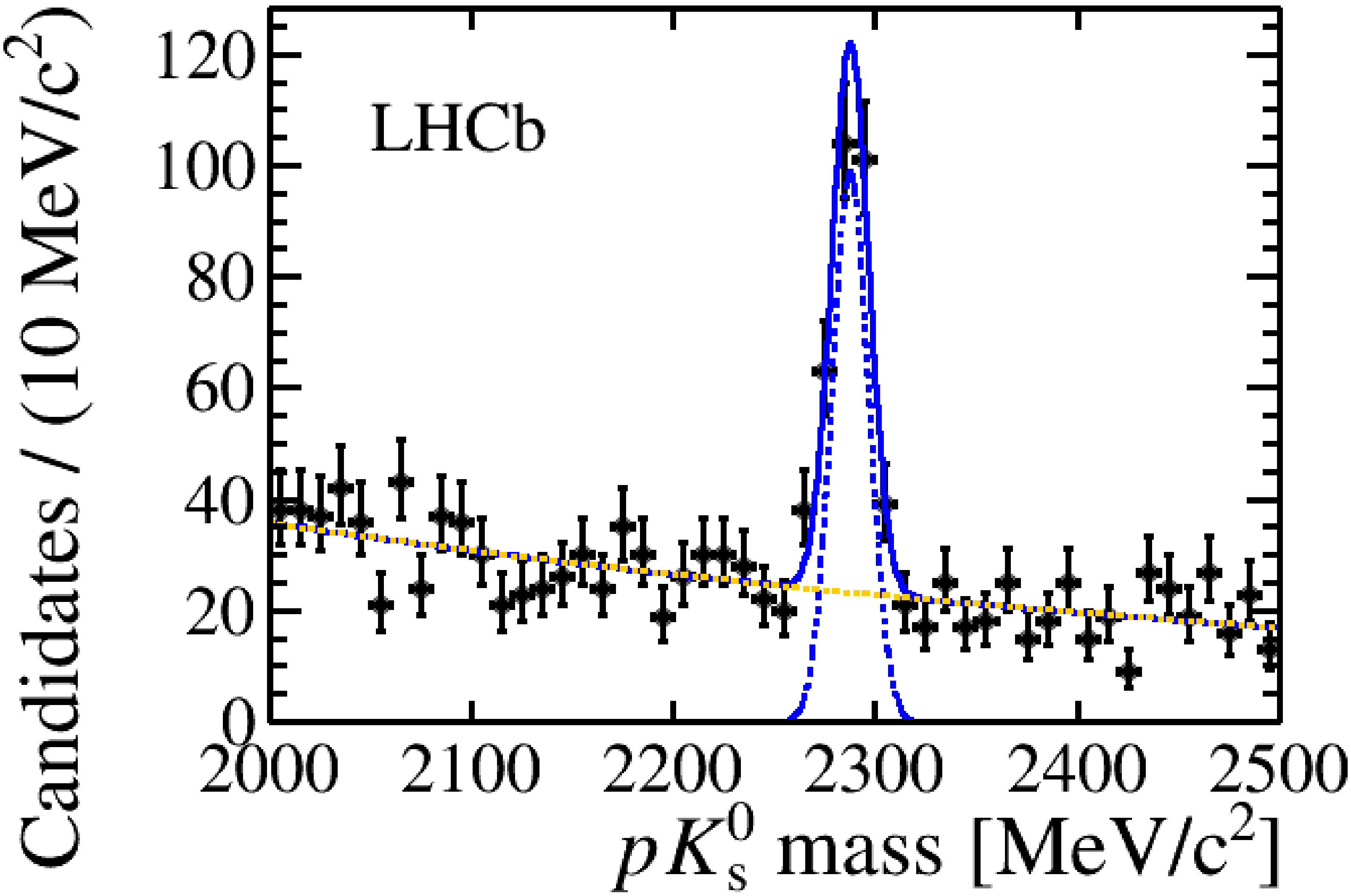
What is the most important stuff for us to start on?

Backup

$\Lambda_b \rightarrow \Lambda_c(\rightarrow pK\pi)\upsilon\mu$



$\Lambda_b \to \Lambda_c(\to pK^0_s)\upsilon\mu$



$\Lambda_b \rightarrow D^0(\rightarrow K\pi)p\upsilon\mu$