$|V_{ub}|$ at LHCb: measurements and future prospects

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on behalf of the LHCb collaboration

Implications workshop 5
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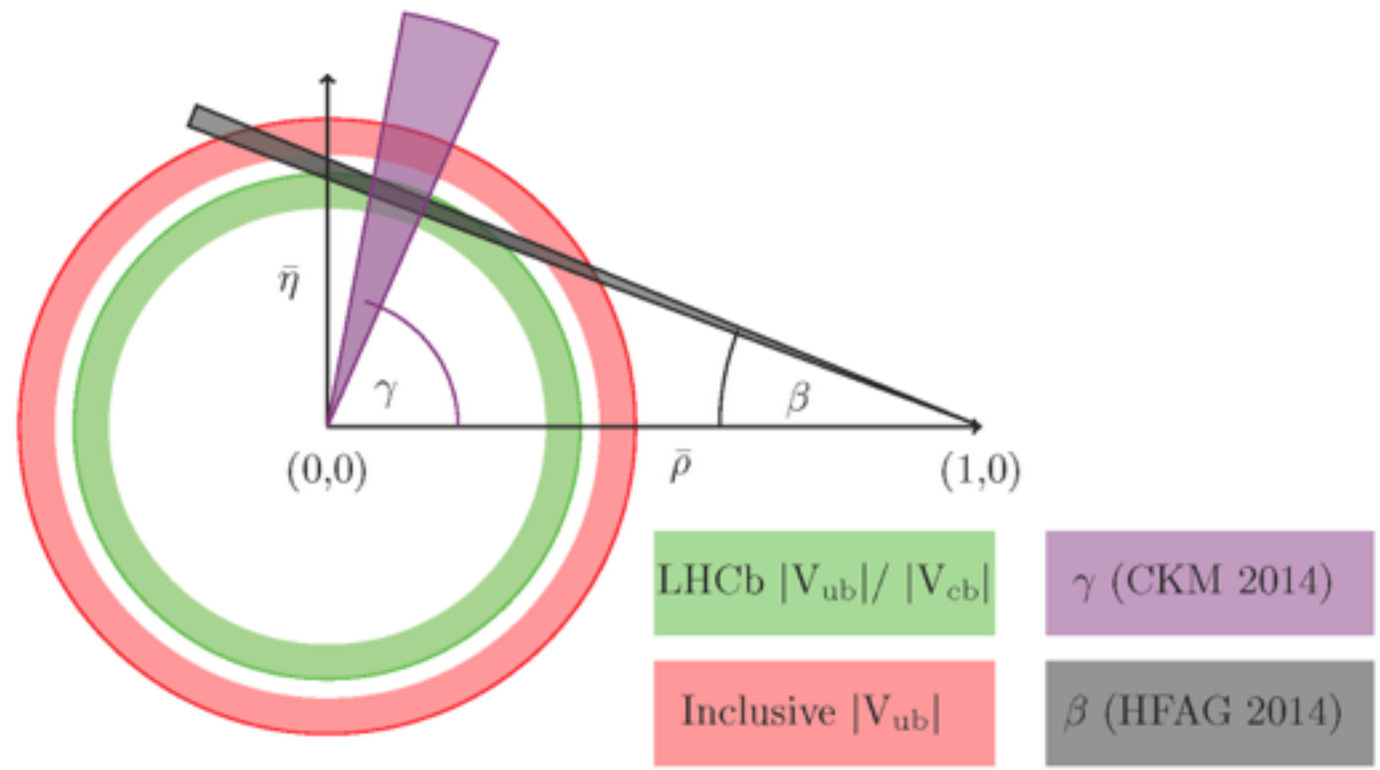
$|V_{ub}|$ is important

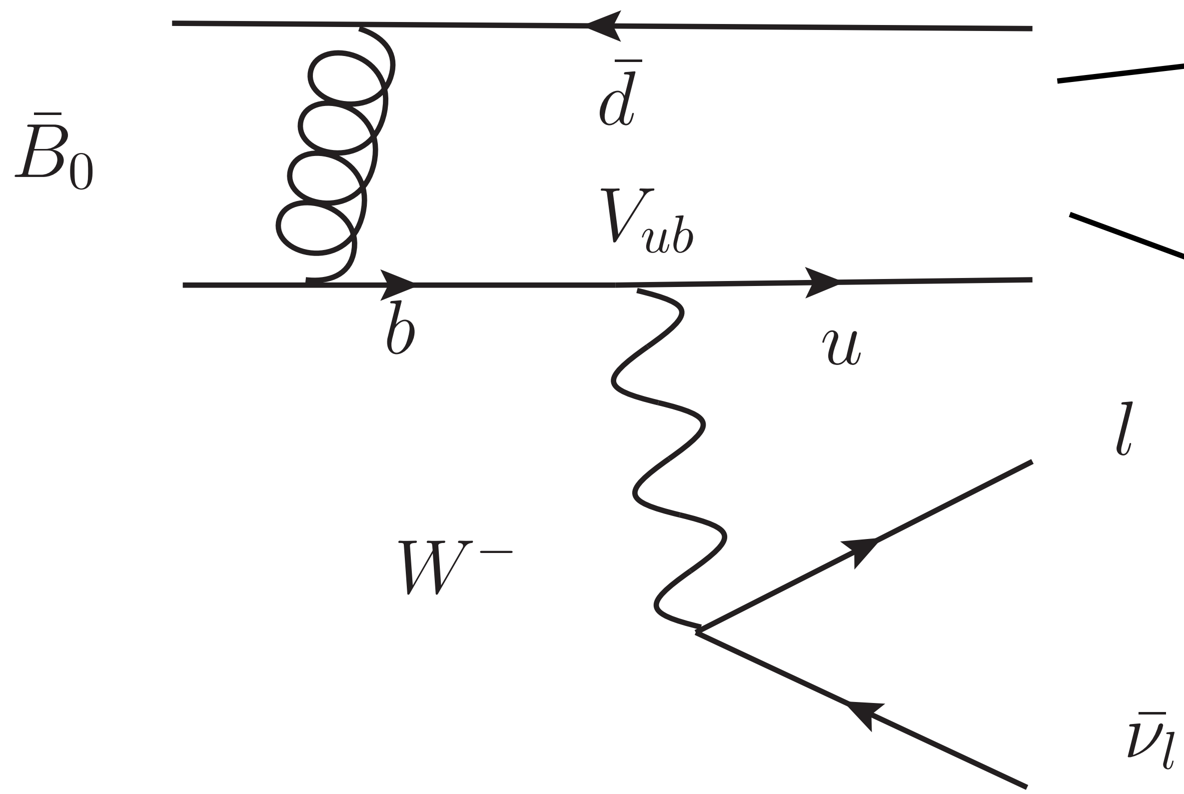
- Measuring $|V_{ub}|$ is useful because:
  - It's the SM benchmark for sin(2β).
  - Predicting $\mathcal{B}(B^+ \to \tau\nu)$
  - Tests of non-perturbative QCD.



- Processes involving V_{ub} might also be sensitive to NP themselves.

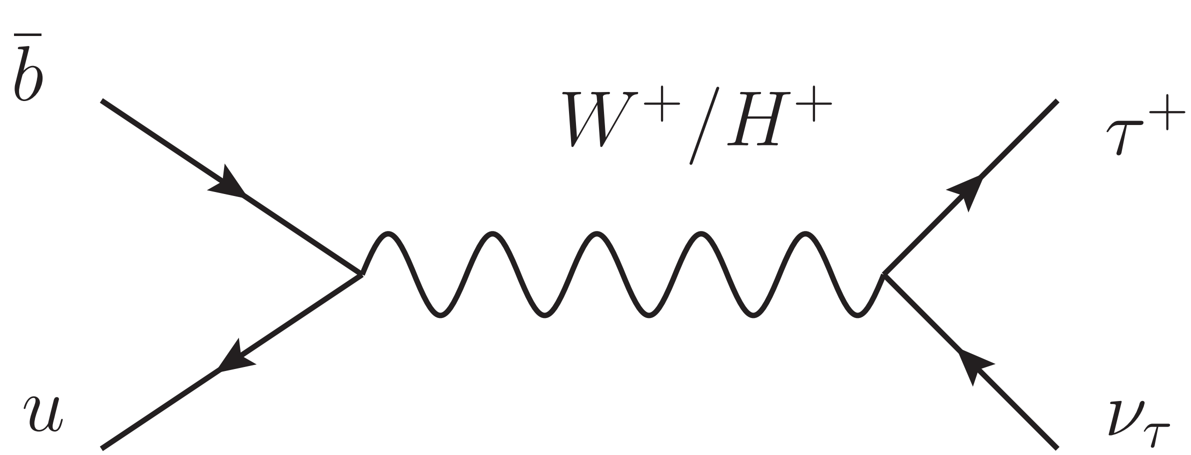
Measuring |V$_{ub}$|

- |V$_{ub}$| is measured using (semi-)leptonic decays.



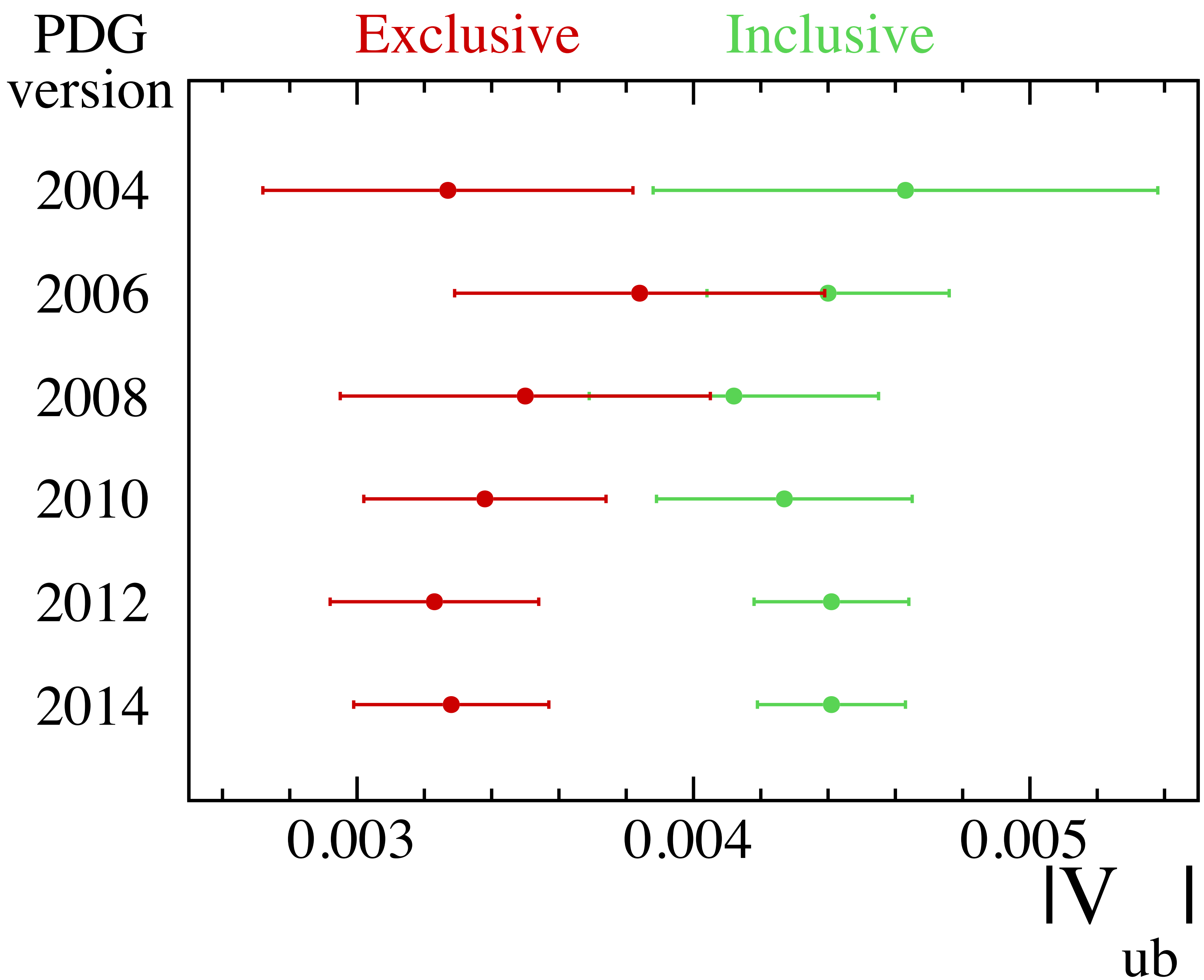
Measure rate exclusive decay, such as $B \to \pi\ell\nu$ rely on LQCD (LCSR).

Measure all semi-leptonic |V$_{ub}$| decays $b \to u\ell\nu$ rely on OPE + quark-hadron duality.



Measure purely leptonic decay $B^+ \to \tau\nu$ rely on LQCD, but uncertainty is small.

Situation as of last PDG version

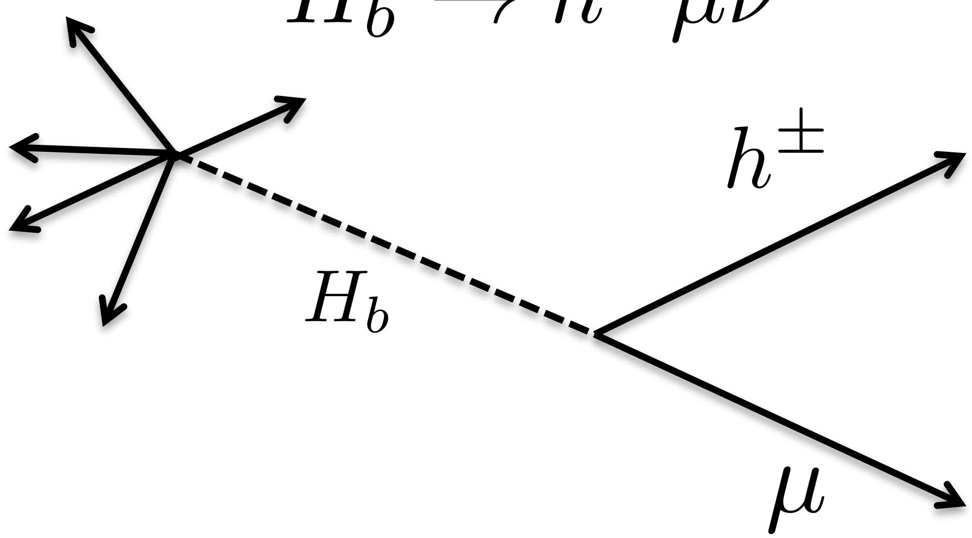


- Leptonic measurement not precise enough to tell which one is which, but tends to prefer inclusive.

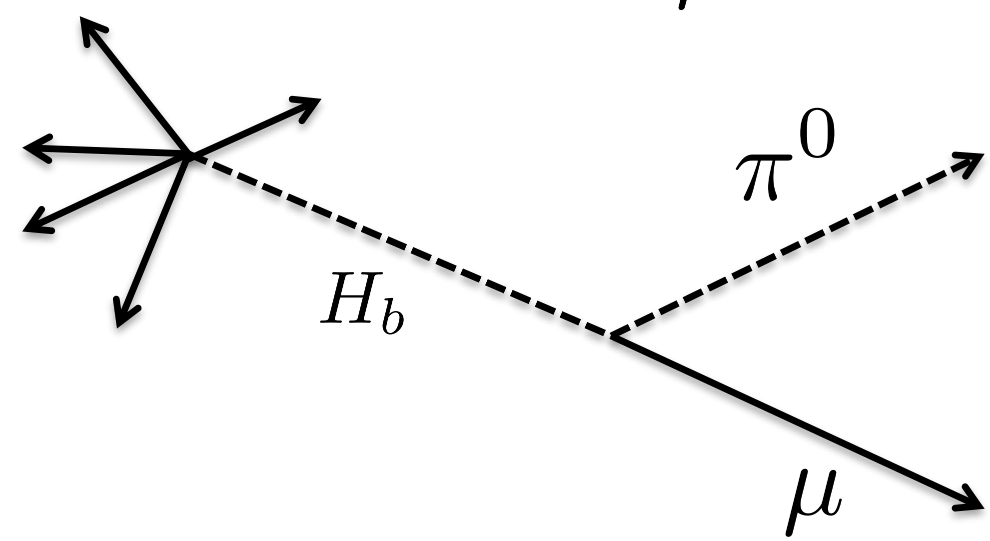
Semi-leptonics at LHCb

Best signature fully charged final state, apart from a single neutrino.

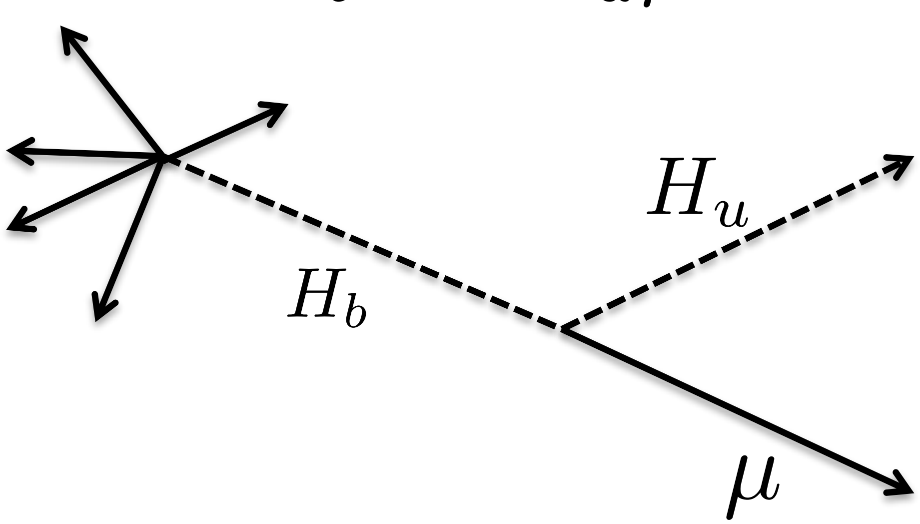
$H_b \to h^{\pm}\mu\nu$



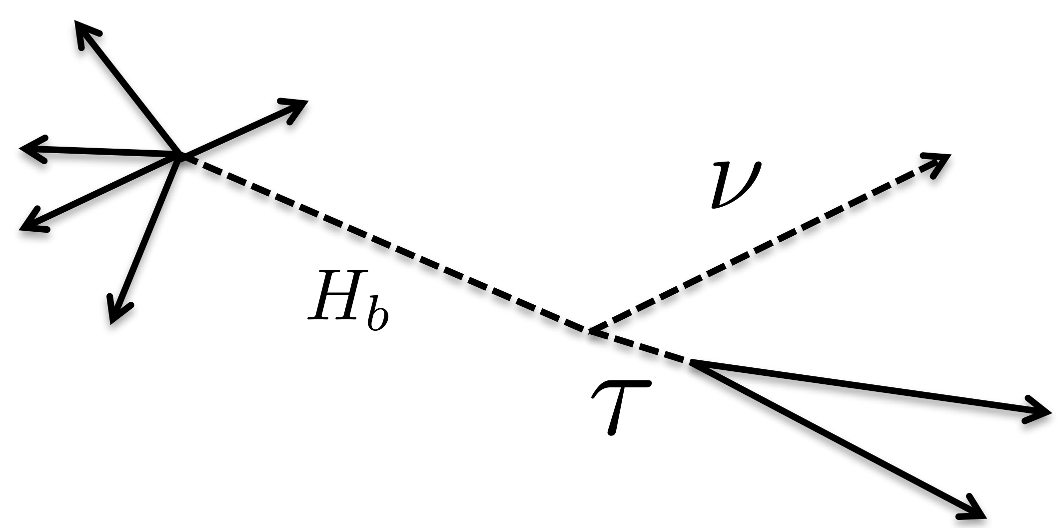
$B^+ \to \pi^0\mu\nu$



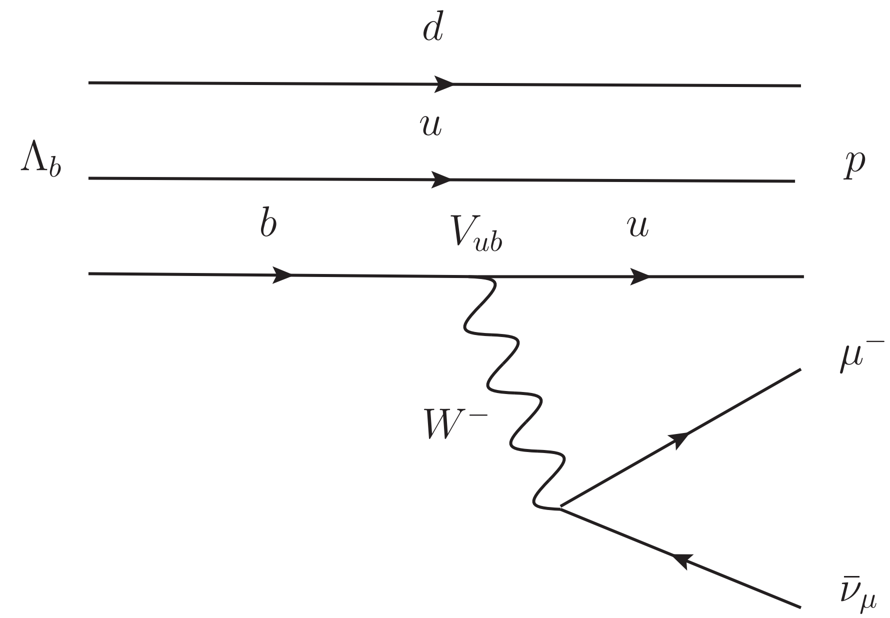
$H_b \to H_u\mu\nu$



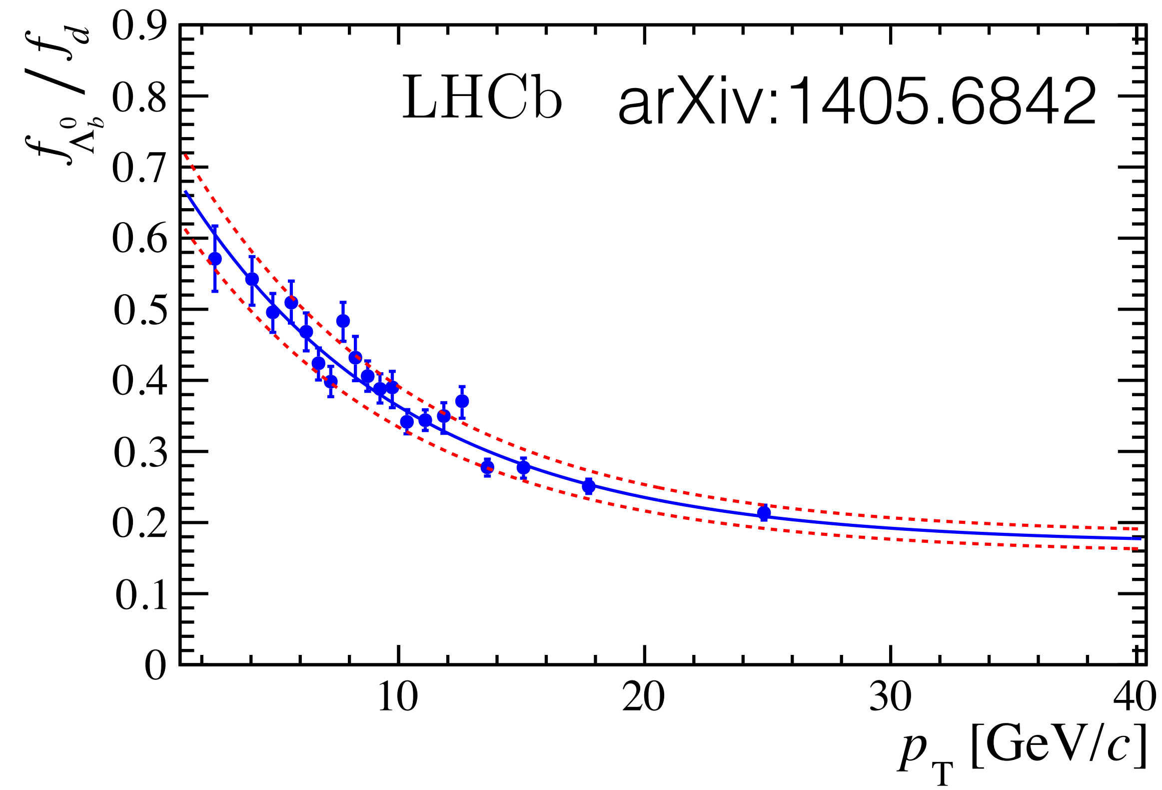
$B^+ \to \tau\nu$



The decay $\Lambda_b^0 \to p\mu\nu$

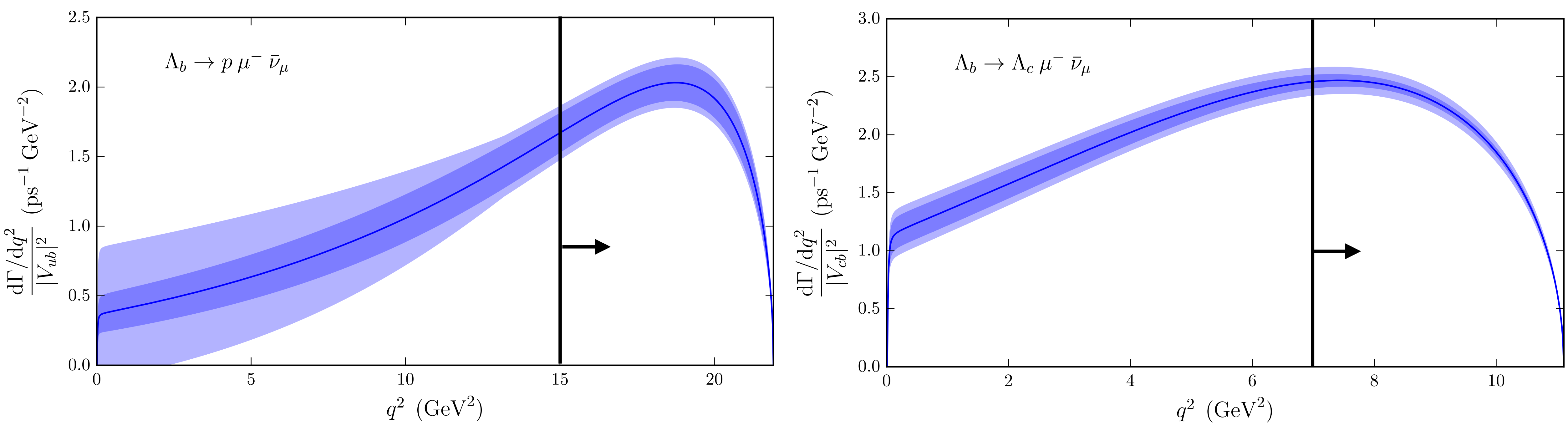


- The decay $\Lambda_b^0 \to p\mu\nu$ is the baryonic version of $B \to \pi\ell\nu$.
- Cleaner at LHCb as protons are rarer than kaons/pions.
- Λ_b baryons not produced at BaBar or Belle experiments but at the LHC produced half as often as B mesons.



Analysis strategy

- Normalise signal yield to V_{cb} decay, $\Lambda_b^0 \to \Lambda_c \mu \nu$
  - Cancel many systematic uncertainties, including the production rate of Λ_b baryons.
- Calculate the branching fraction ratio at high q^2, only use data in the region with lattice points.



Plots from W. Detmold, C. Lehner, S. Meinel, arXiv:1503.01421

Results

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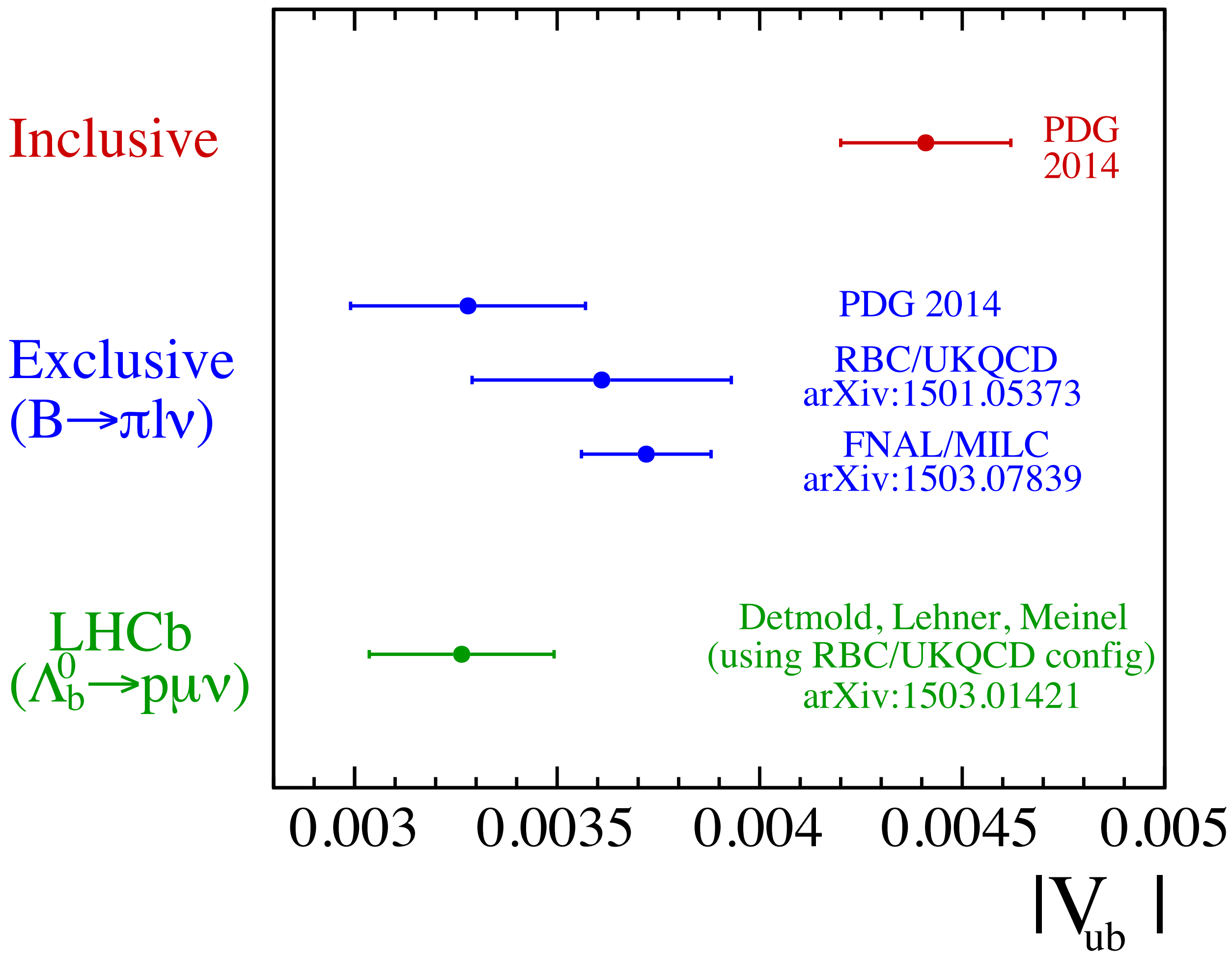
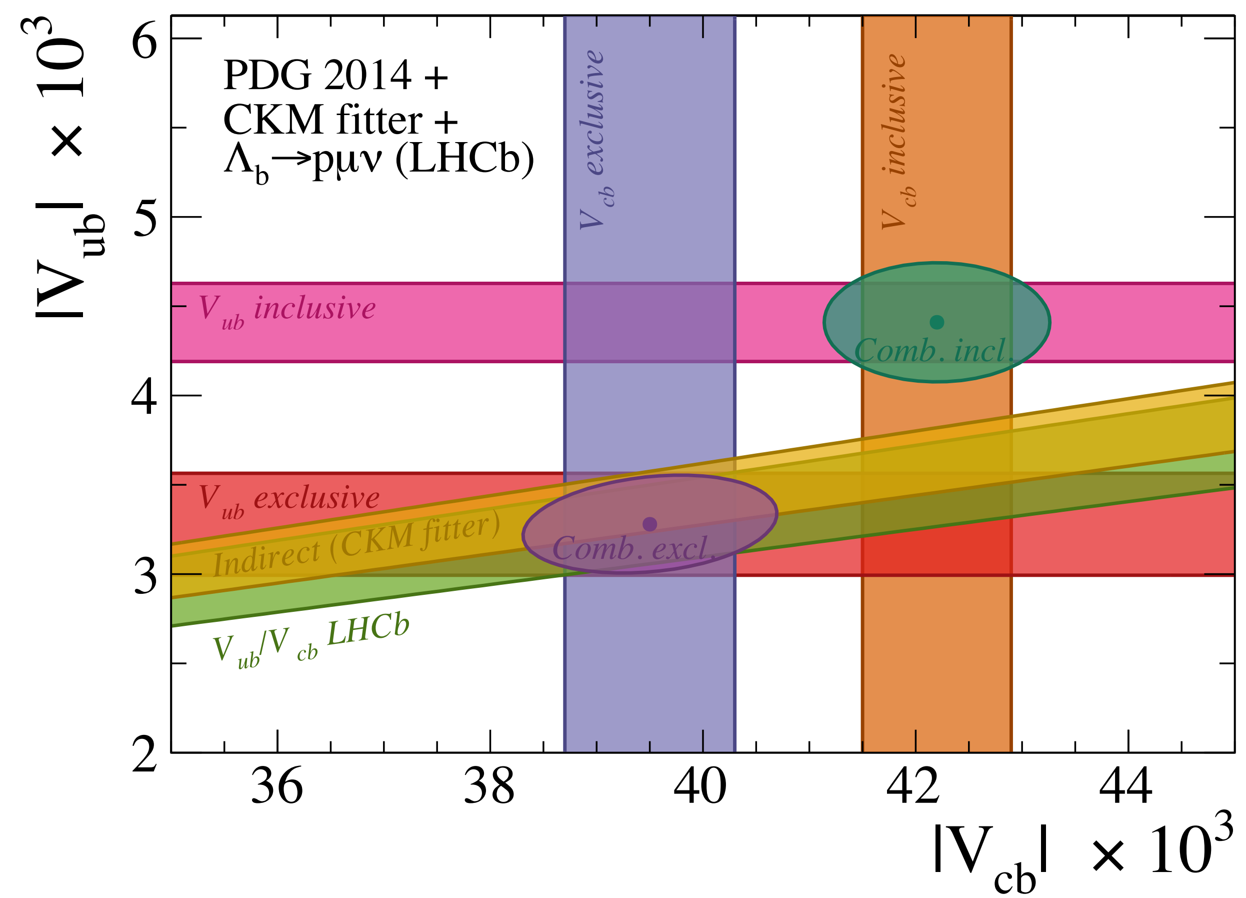


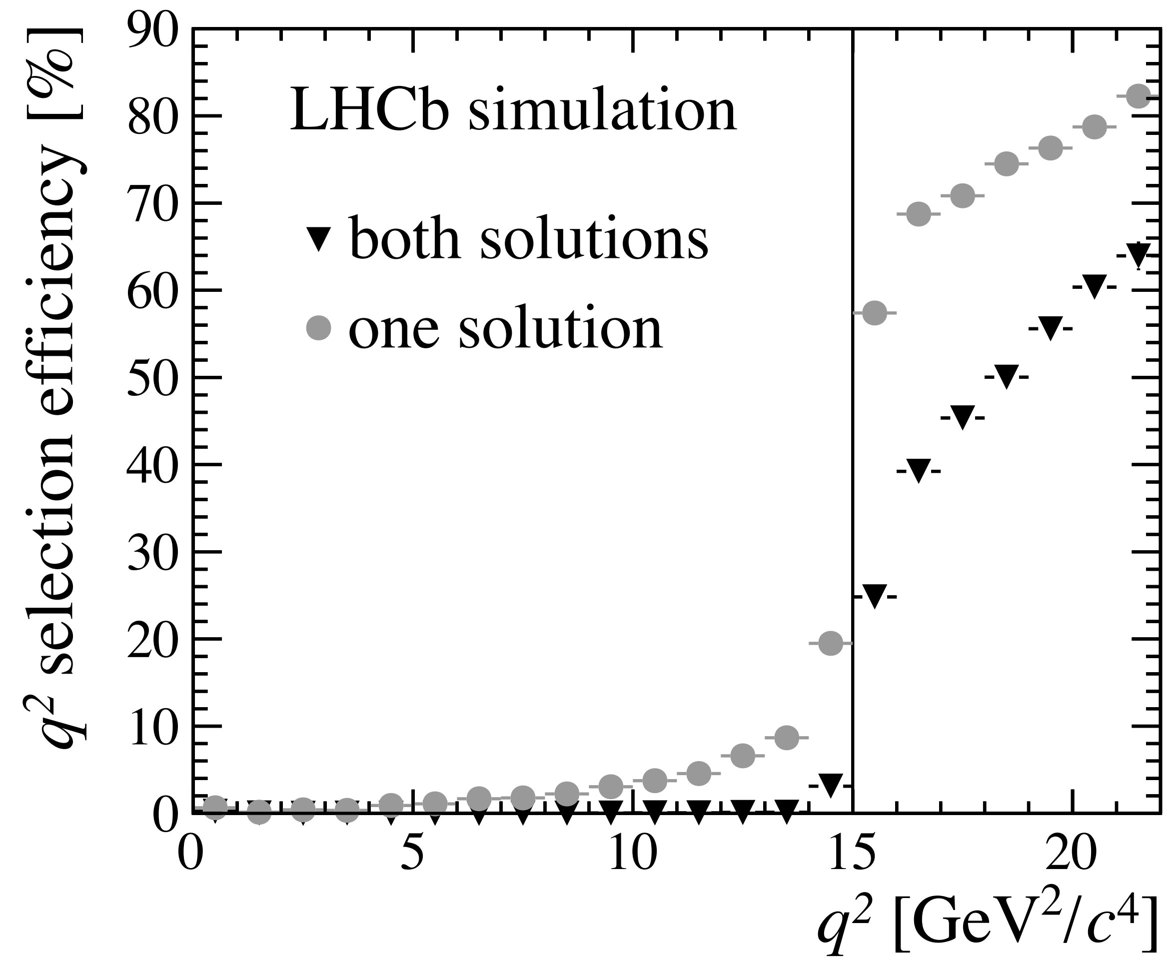


- Confirms tension inclusive/exclusive tension.
- Precision split between lattice/experimental data.
  - From experimental side need to improve $\mathcal{B}(\Lambda_c \to pK\pi)$

Differential measurement?

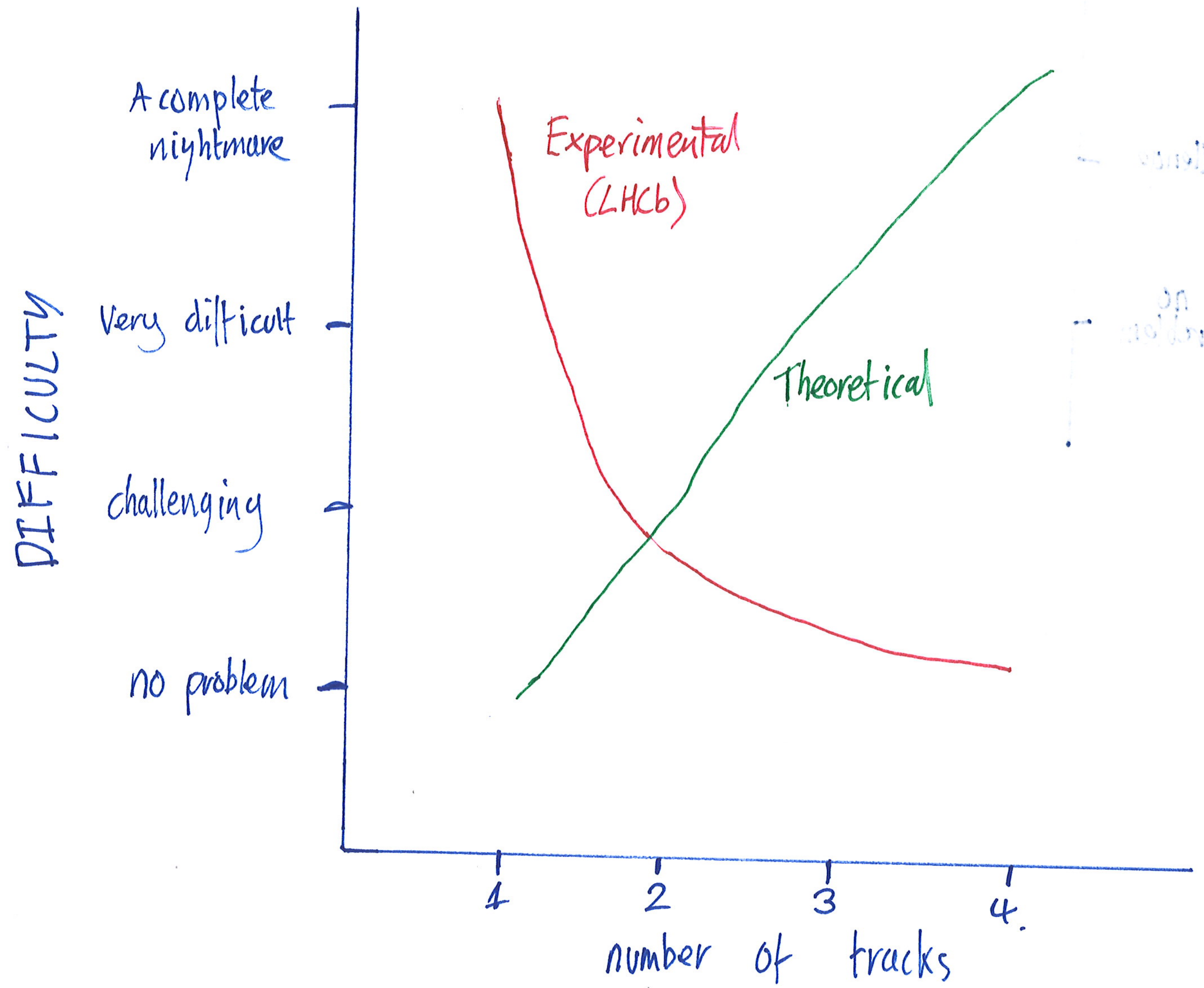
- Should we do a differential measurement of $\Lambda_b^0 \to p\mu\nu$?
  - Resolution is pretty wide compared to B-factories.
  - Do not rely heavily on z-expansion as we are not extrapolating.

We would probably need more data to understand migration between different bins.



Beyond $\Lambda_b^0 \to p\mu\nu$

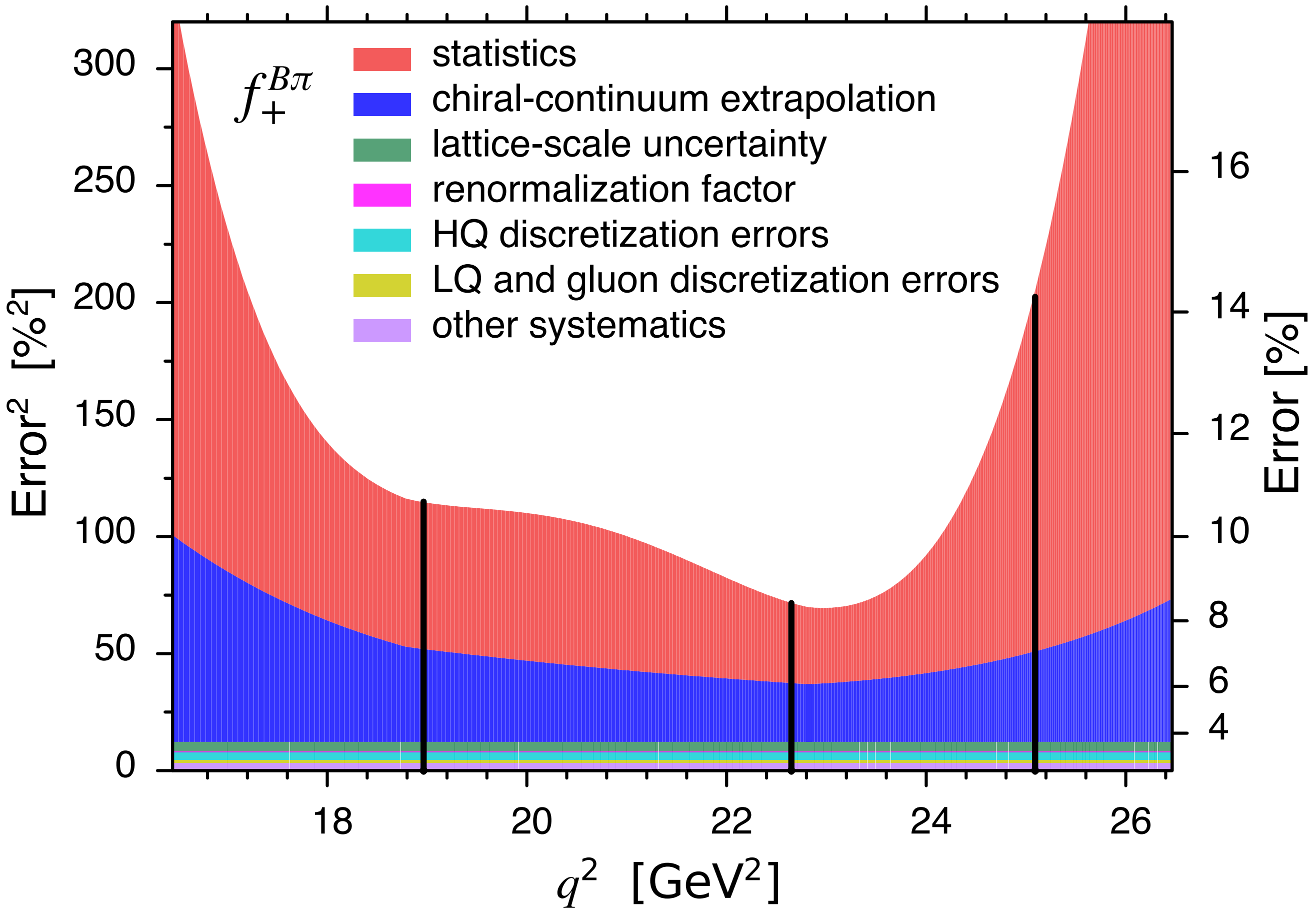
- There are several decays to consider.
  - Golden modes: $B \to \pi\ell\nu$, $B_s^0 \to K^+\mu^-\nu$
  - Excited modes: $B \to \rho\mu\nu, \Lambda_b^0 \to N^*\mu\nu, B \to p\bar{p}\mu\nu \ldots$
- Adding extra tracks to final state reduces background and improves signal resolution.

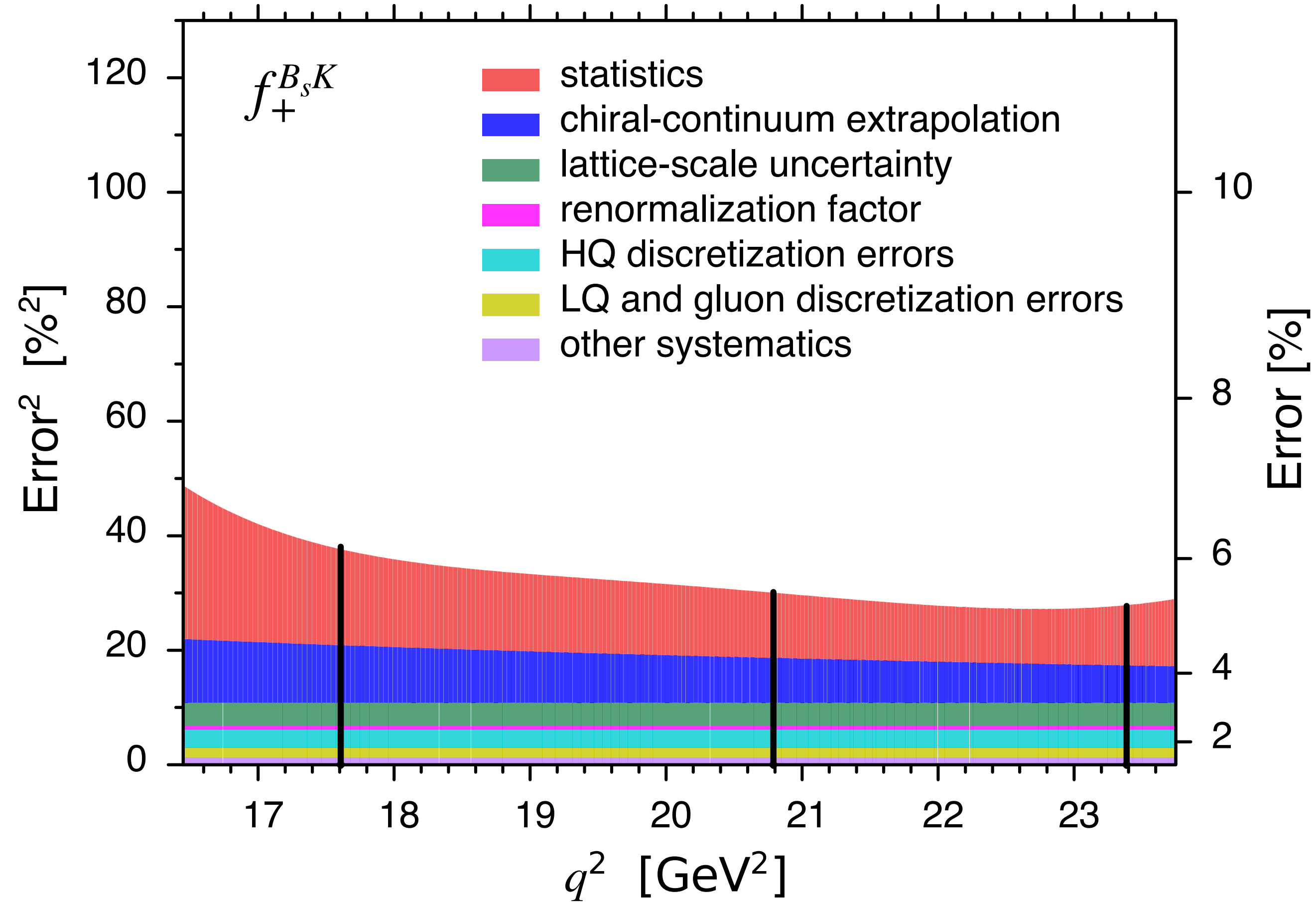


$B_s^0 \to K^+\mu^-\nu$

- The decay $B_s^0 \to K^+\mu^-\nu$ has the potential to produce the most precise result there is.

plots from RBC/UKQCD group, arXiv:1501.05373





- The same lattice data produces twice as good precision for $B_s^0 \to K^+\mu^-\nu$ w.r.t. $B \to \pi\ell\nu$

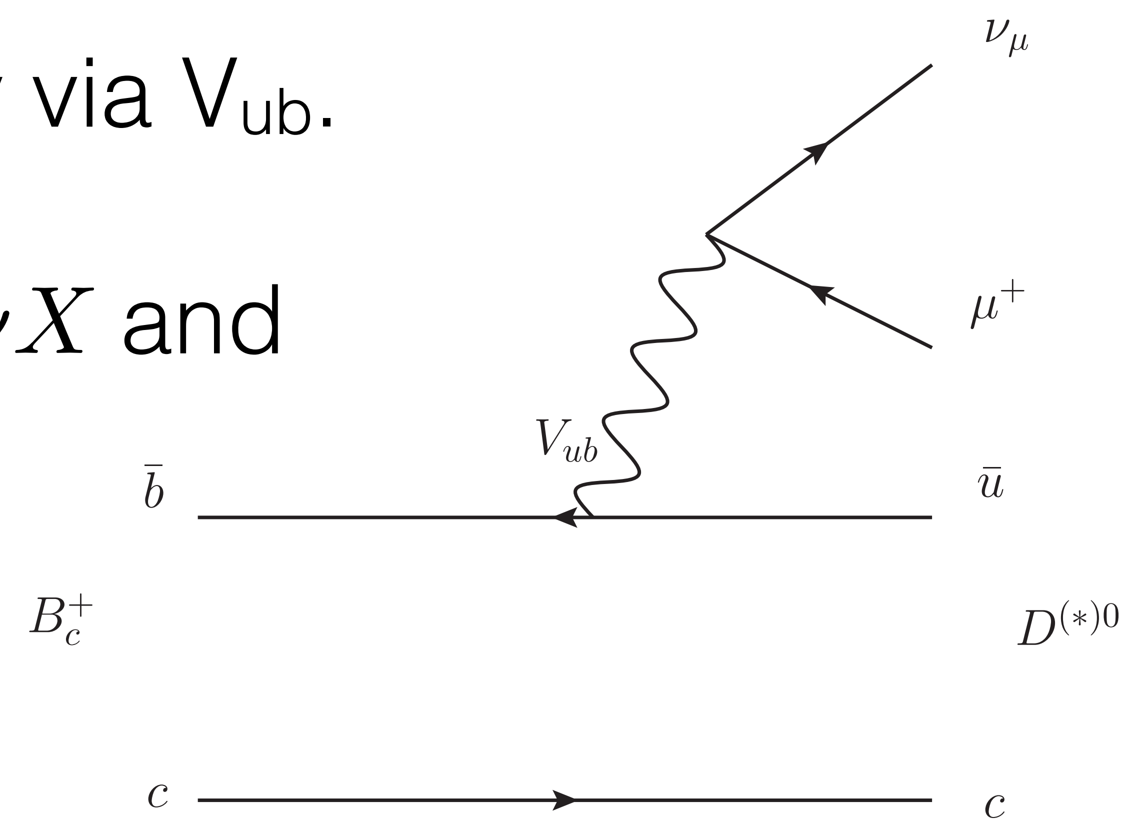
$B_s^0 \to K^+\mu^-\nu$ vs $\Lambda_b^0 \to p\mu\nu$

Decay	Λ_b^0	B_s^0
theory error	5%	??
prod frac	20%	10%
BF	4×10^{-4}	1×10^{-4}
$\mathcal{B}(X_c)$ error	${}^{+5.3}_{-4.7}\%$	$\pm 3.9\%$
background	Λ_c^+	$\Lambda_c^+, D_s, D^+, D^0$

- $B_s^0 \to K^+\mu^-\nu$ is clearly more difficult than $\Lambda_b^0 \to p\mu\nu$ but has better ultimate precision.
- We are working hard on this, stay tuned for next year.

$|V_{ub}|$ with B_c mesons

- B_c mesons can also decay via V_{ub}.
- Signature is $B_c^+ \to D^0 \mu^+ \nu X$ and $B_c^+ \to D^+ \mu^+ \nu X$



- We have around 10,000 $B_c^+ \to J/\psi \mu^+ \nu X$ candidates from LHCb-PAPER-2013-063.
  - Expect about 100 $B_c^+ \to D^0 \mu^+ \nu X$ candidates.
- Could we get theoretical control to determine $|V_{ub}|/|V_{cb}|$ ratio?

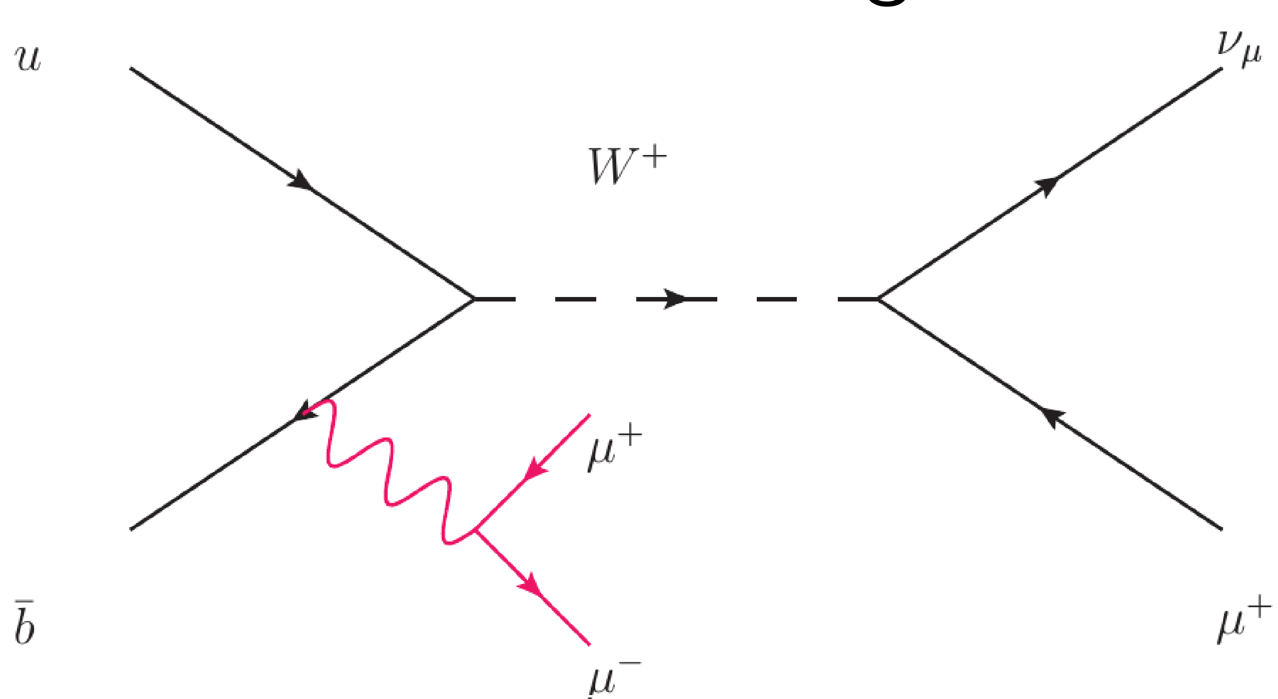
Leptonic decays

- Purely leptonic V_{ub} decays are difficult, if not impossible to find at LHCb.

    - $B^+ \to \tau\nu$ is clearly a waste of time.

- $B^+ \to \mu\nu$ better, however helicity suppression makes the SM BF too rare to be useful for $|V_{ub}|$.

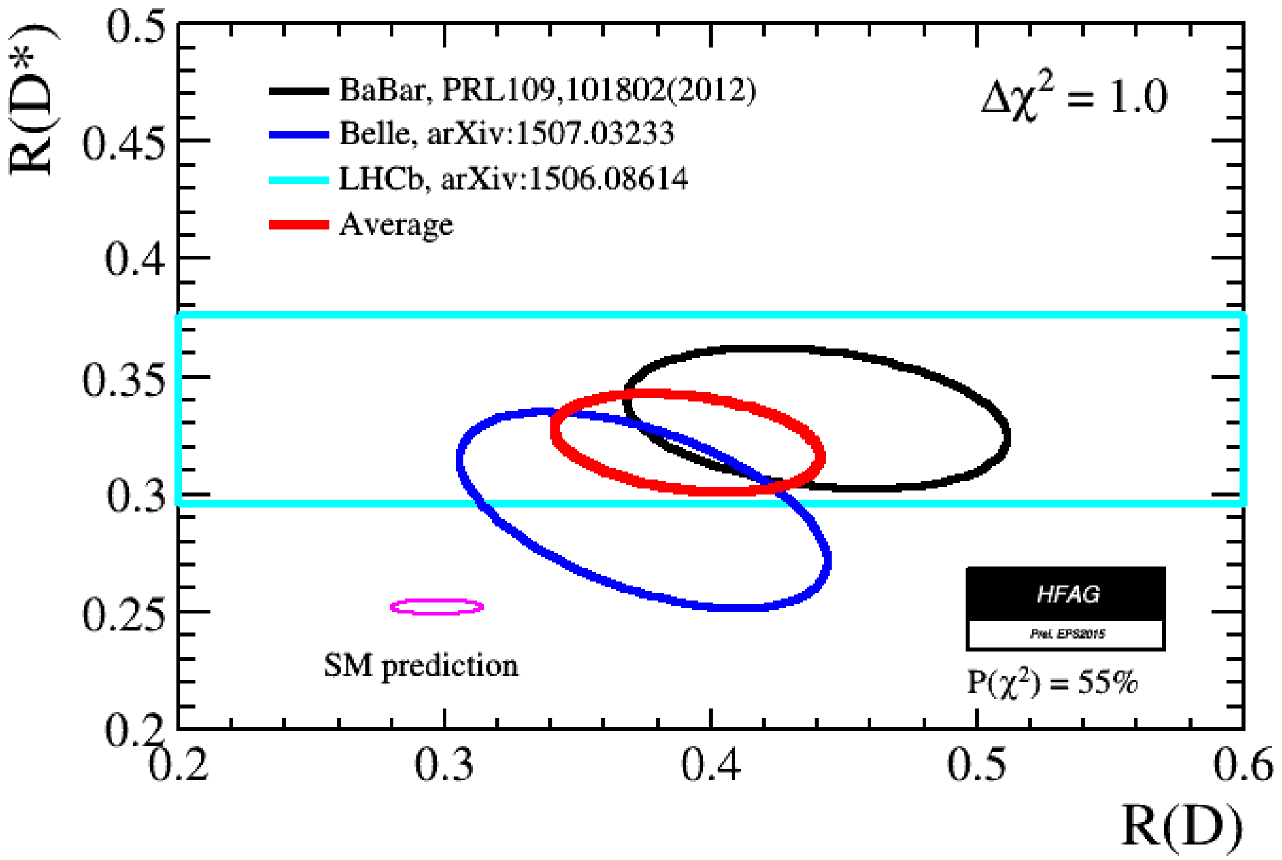
- Radiate off initial leg to remove helicity suppression.



- Analysis on-going. We plan to remove events with q^2 above $1\mathrm{GeV}/c^2$ - is this ok?

V_{ub} τ decays

- If there is NP in V_{cb} τ decays, what about V_{ub}?
  - Less SM background.



- Excited states can be used here.

$$R(N^*) = \frac{\mathcal{B}(\Lambda_b \to N^* \tau\nu)}{\mathcal{B}(\Lambda_b \to N^* \mu\nu)}$$

$$R(p\bar{p}) = \frac{\mathcal{B}(B \to p\bar{p}\tau\nu)}{\mathcal{B}(B \to p\bar{p}\mu\nu)}$$

What kind of limits would be interesting, given constraints on $\mathcal{B}(B \to \pi\tau\nu)$ from Belle (arXiv:1509.06521)?

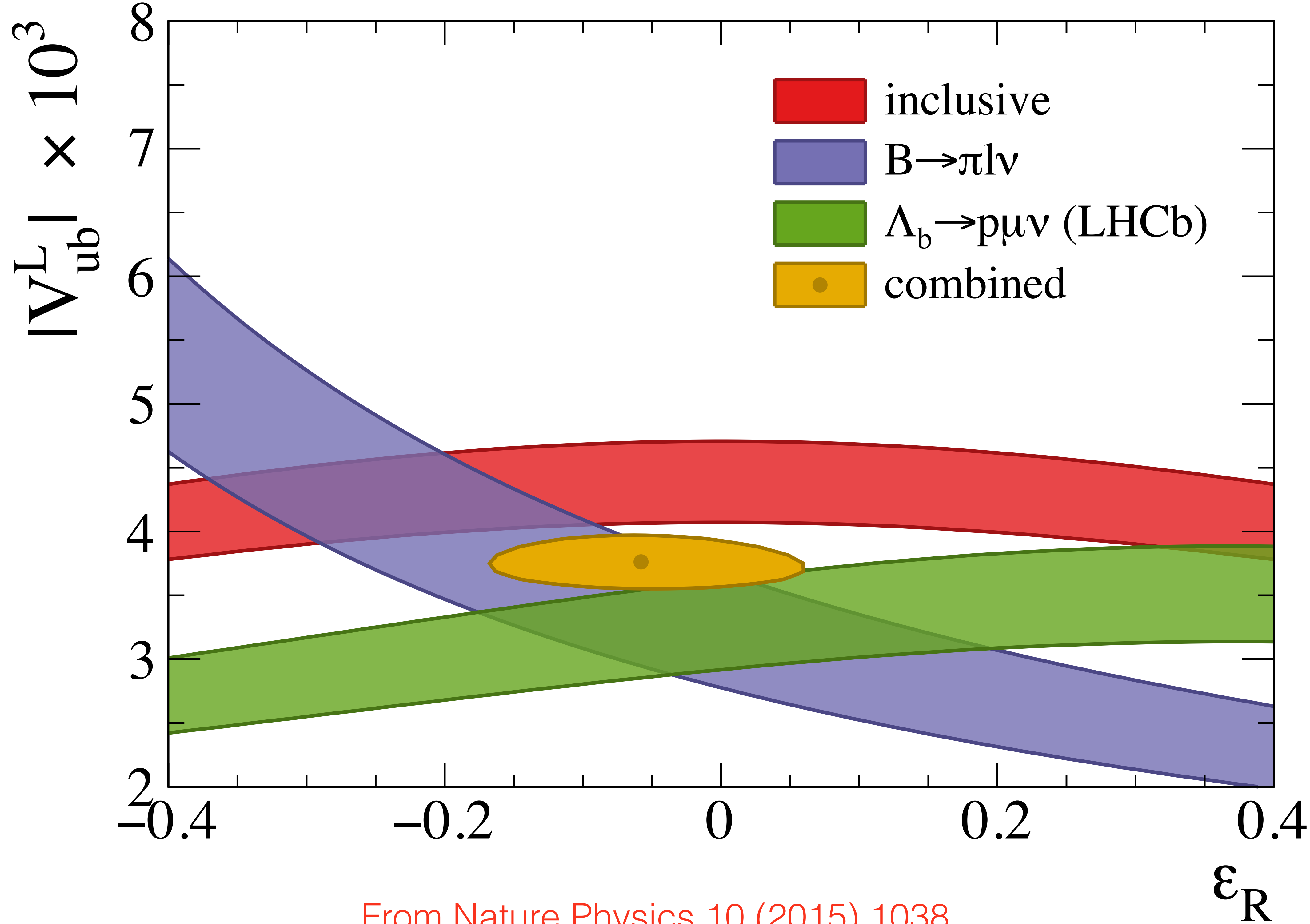
Other ideas

- Kaon veto applied in inclusive measurement to suppress V_{cb} background.
- Can the decays $B \to KK\pi\mu\nu$ and $B \to KK\mu\nu$ help control the efficiency of this (I. Bigi, arXiv:1507.01842)?
- Another distinctive signature is $B \to p\bar{p}\mu\nu$. Could we learn anything about $|V_{ub}|$ or the hadronic structure?
- What about angular analyses of e.g. $B \to \rho\mu\nu$, is there room left for significant deviations from the SM predictions?

Summary

- LHCb has measured $|V_{ub}|$ using $\Lambda_b^0 \to p\mu\nu$ decays.
- The $|V_{ub}|$ field is relatively new to LHCb, but is expanding rapidly.
- We will obviously try to do everything we can. However, input to what is particularly interesting or new ideas are very welcome.

RH currents



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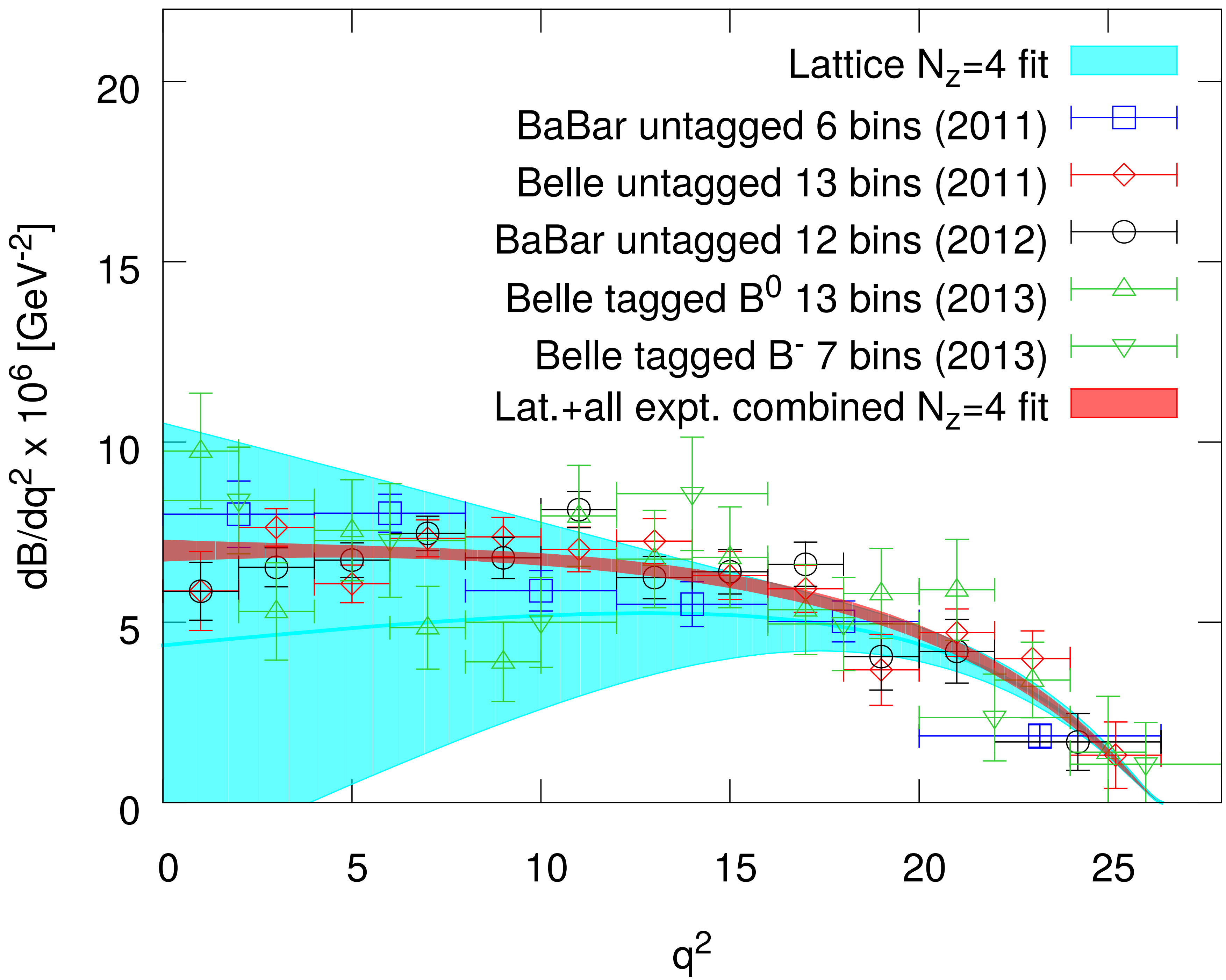
B—>πlν



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