

LHC results on tree-level beauty decays

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On behalf of the LHCb collaboration

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EPS 2017 Venice

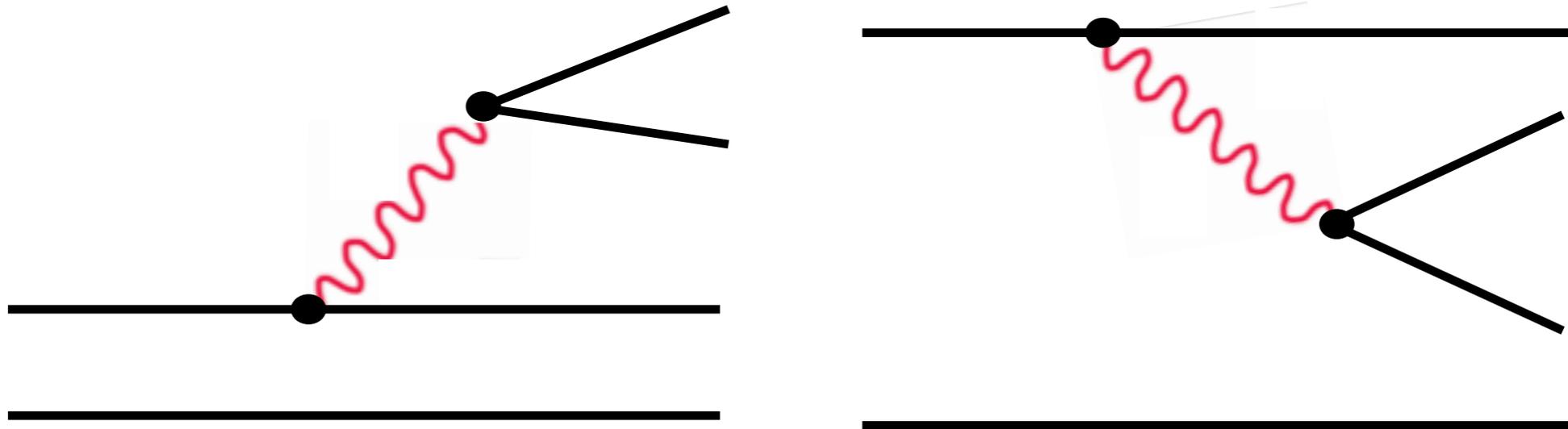


Topics covered with more detail in talks of

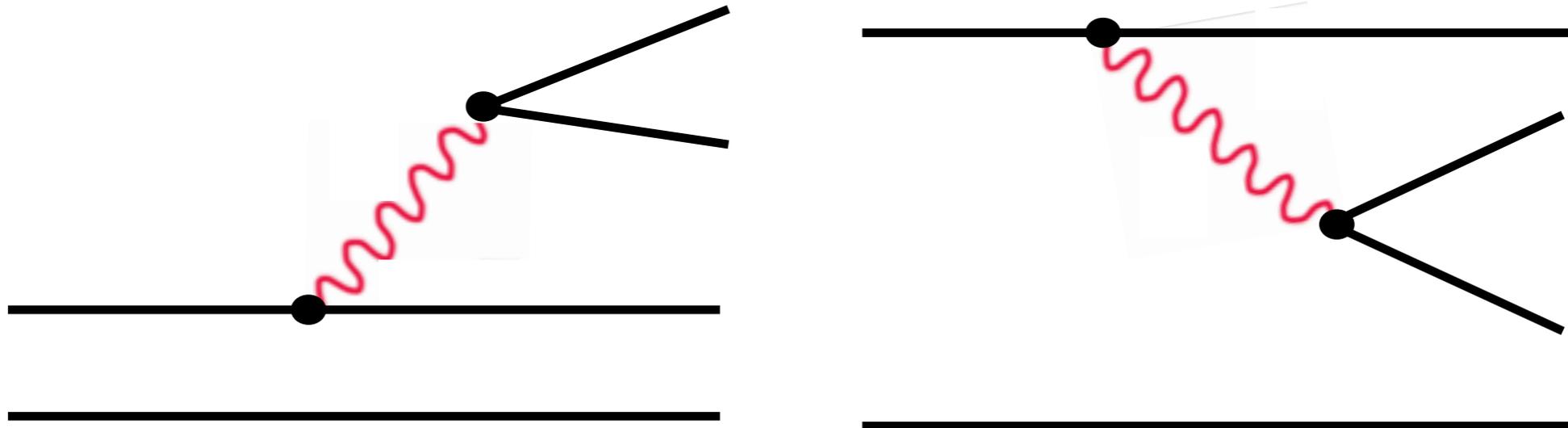
Concezio Bozzi *Recent results from LHCb on semileptonic decays of b-hadrons*

Donal Hill *Measurements of the CKM angle gamma at LHCb*

Tree-level decays



Tree-level decays



Outline:

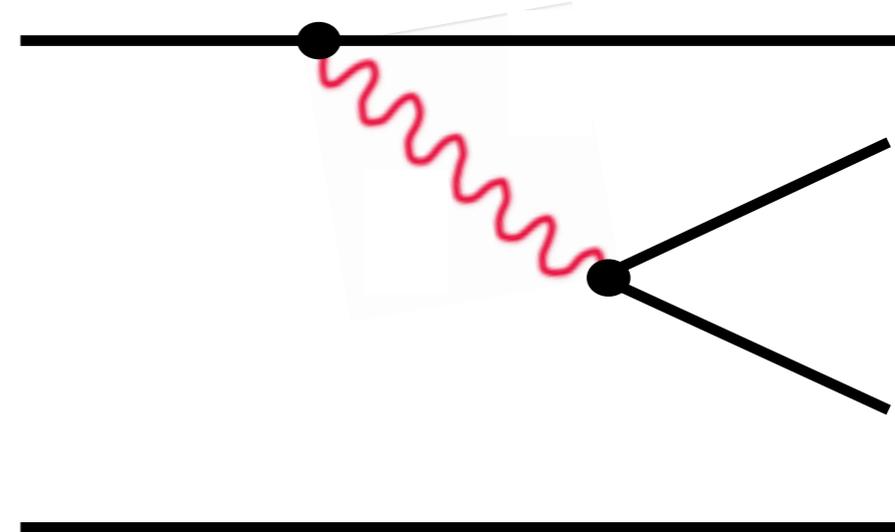
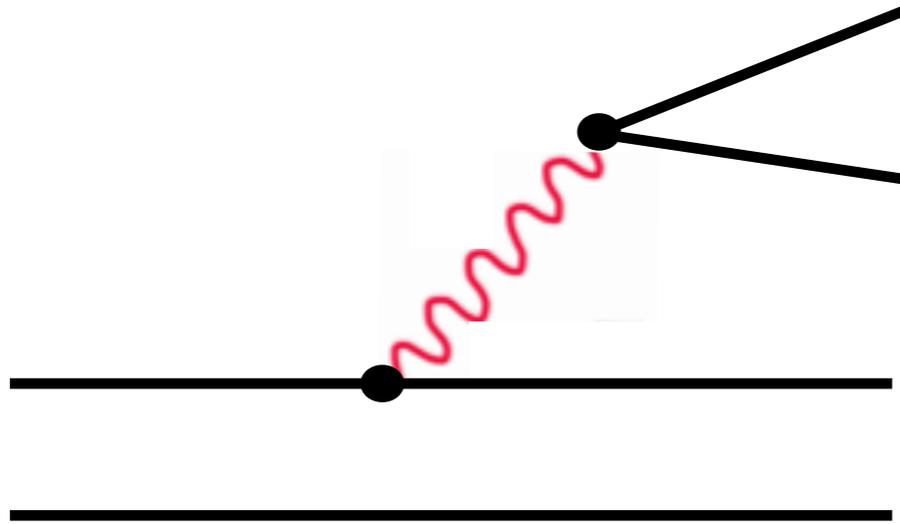
Semileptonic decays

- b baryon V_{ub} and V_{cb} decays, and future LHCb prospects
- LHCb results on $R(D^*)$

Hadronic decays

- LHCb updates on γ

Tree-level decays



Outline:

Semileptonic decays

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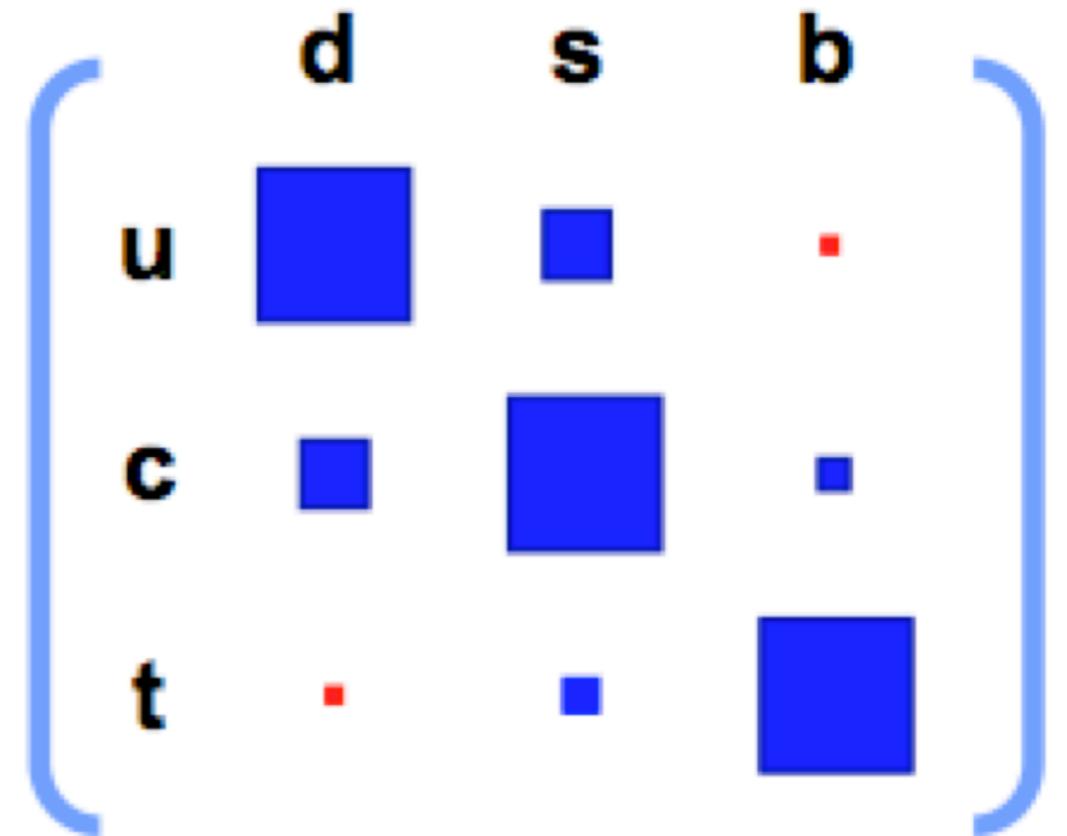
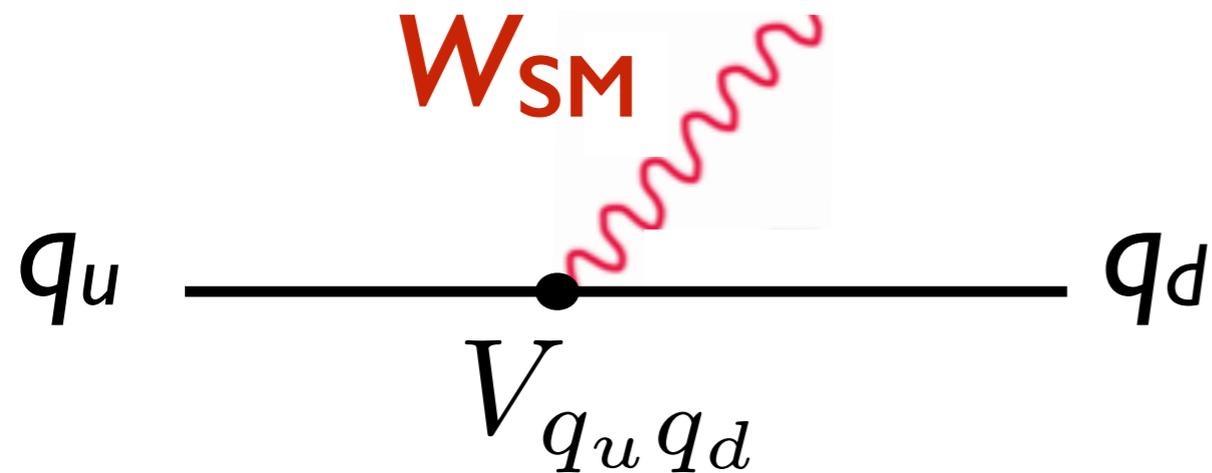
Concezio Bozzi

Hadronic decays

- LHCb updates on γ

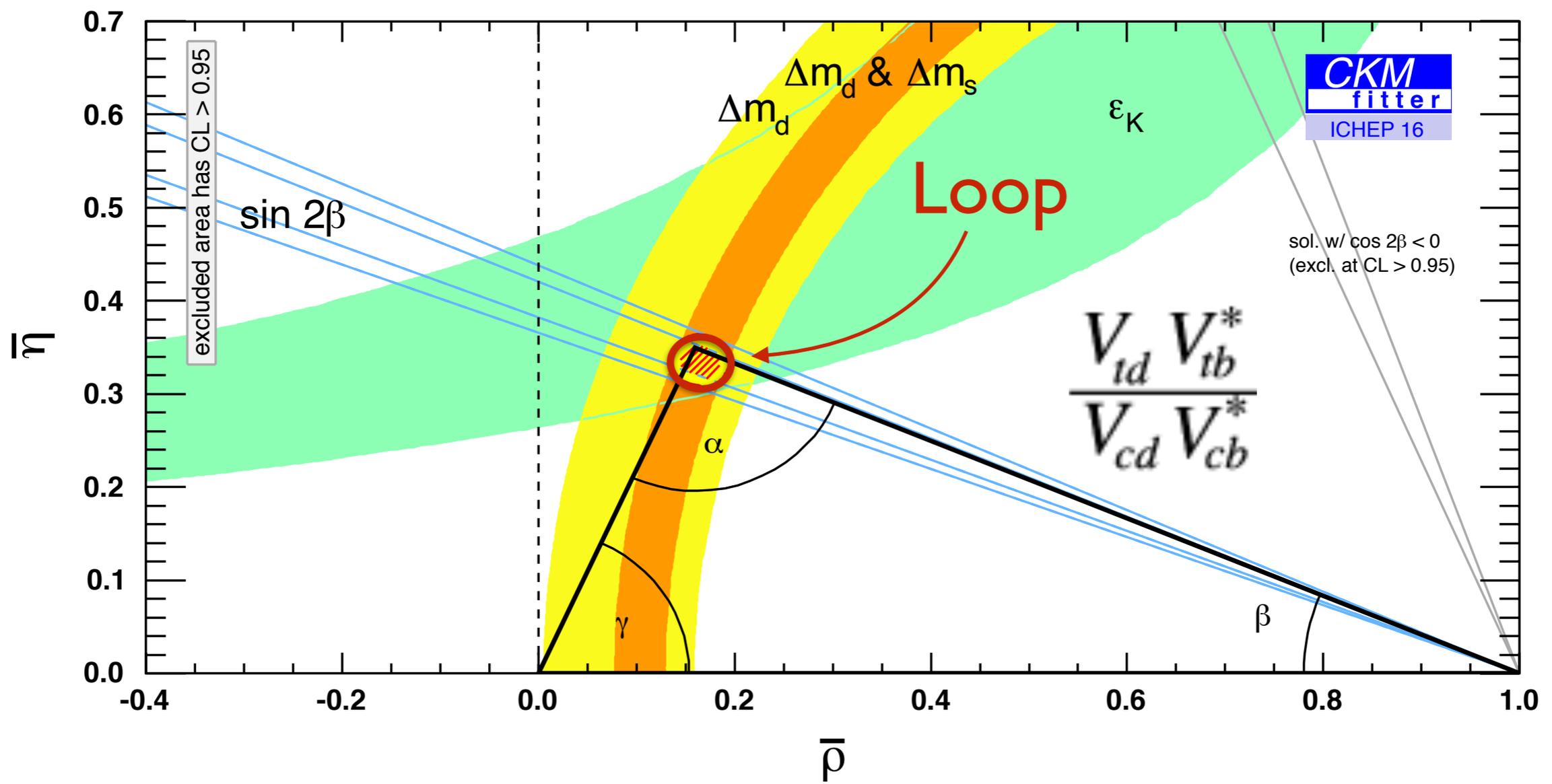
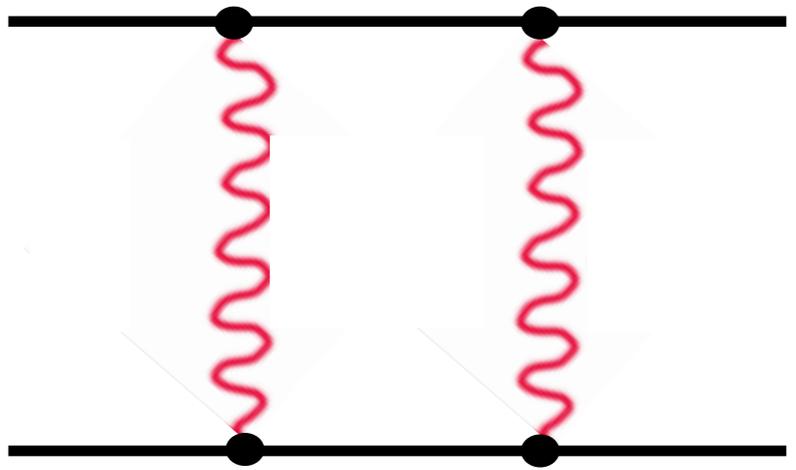
Donal Hill

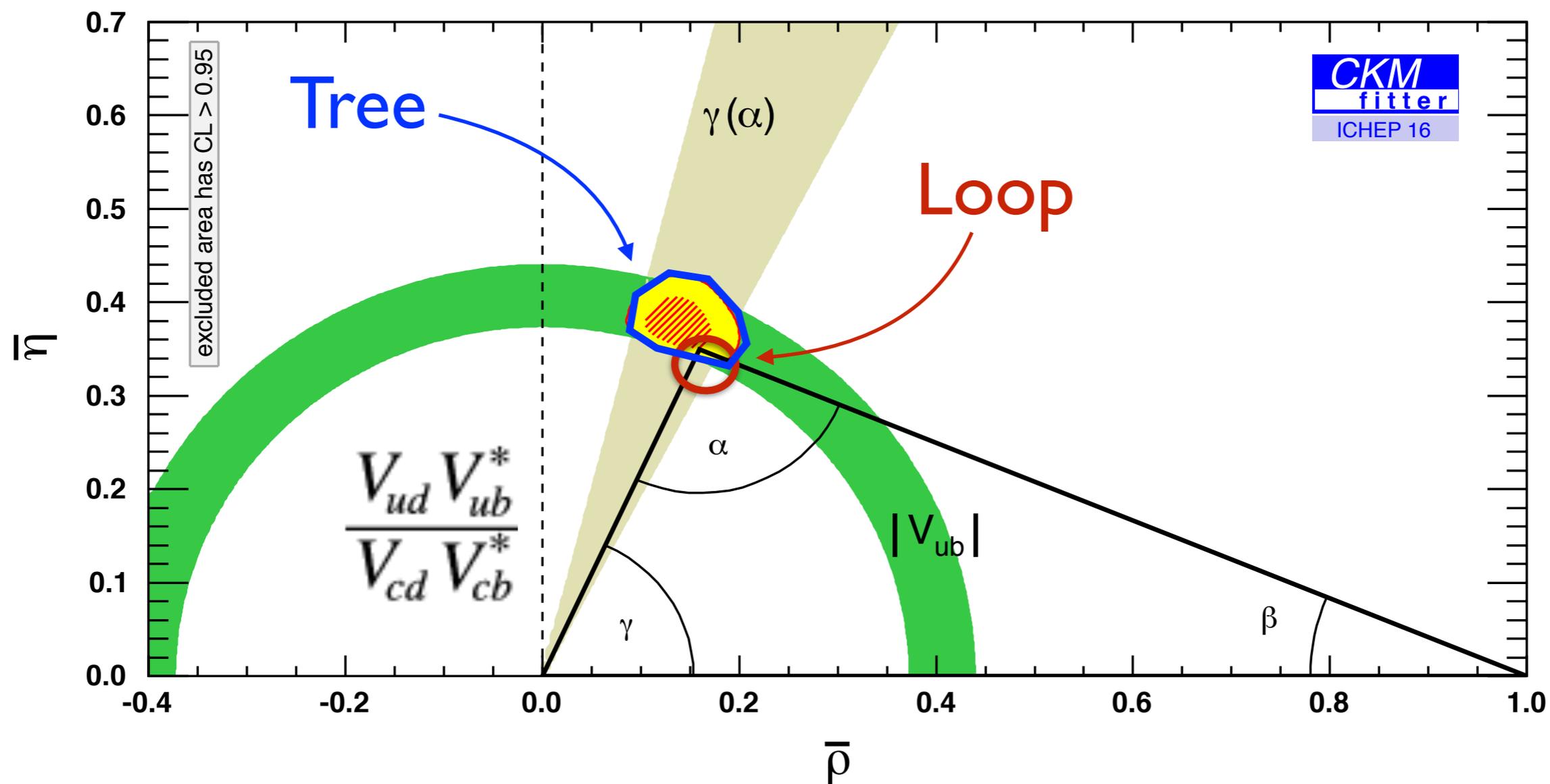
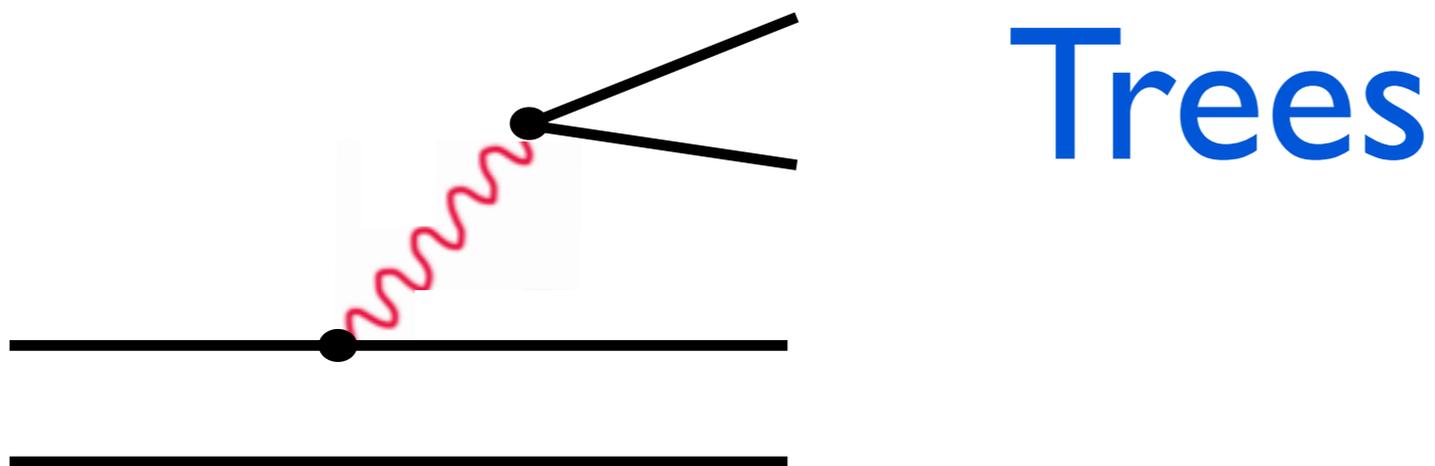
CKM unitarity



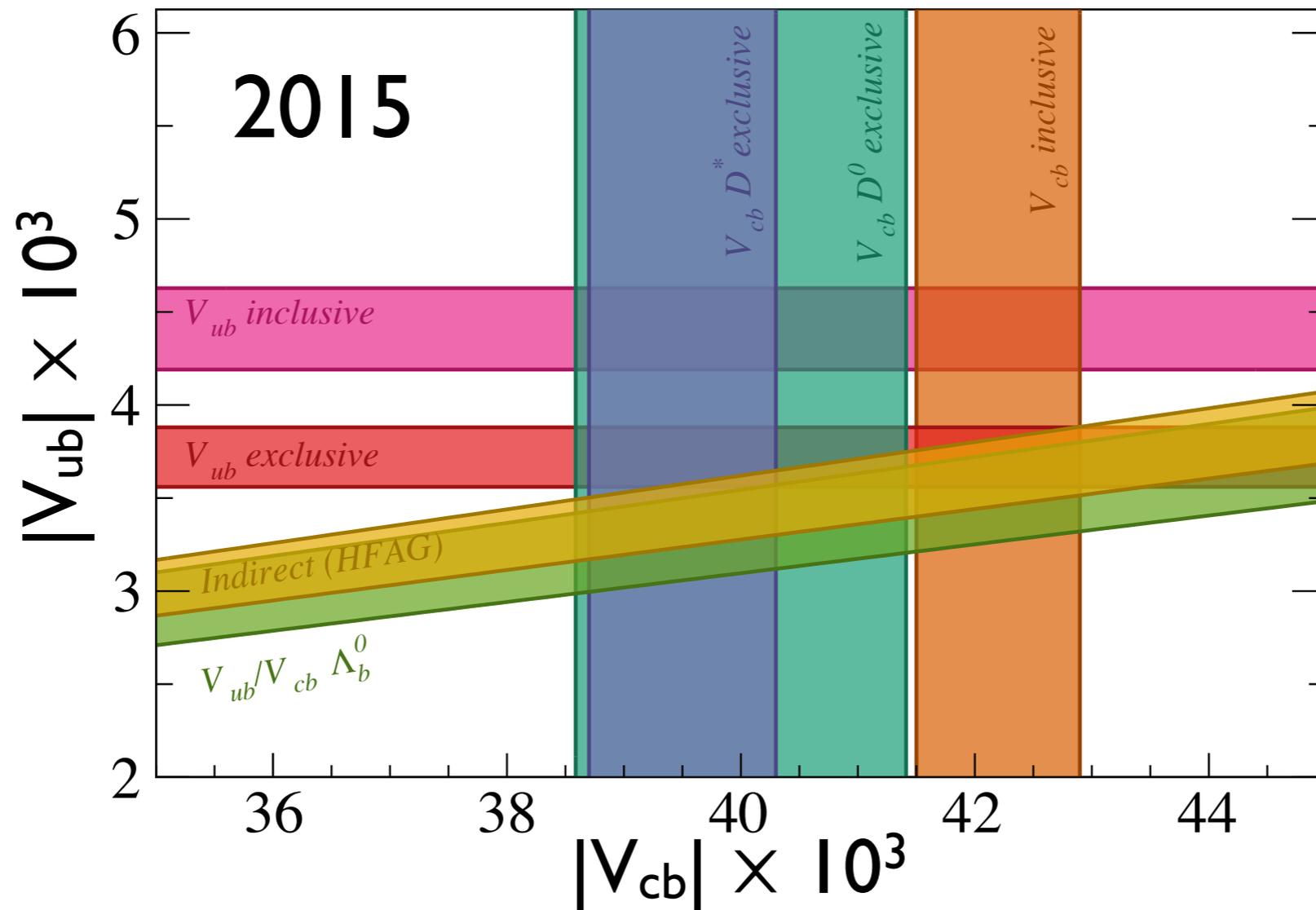
The only source of quark flavour violation and CP violation?

Loops

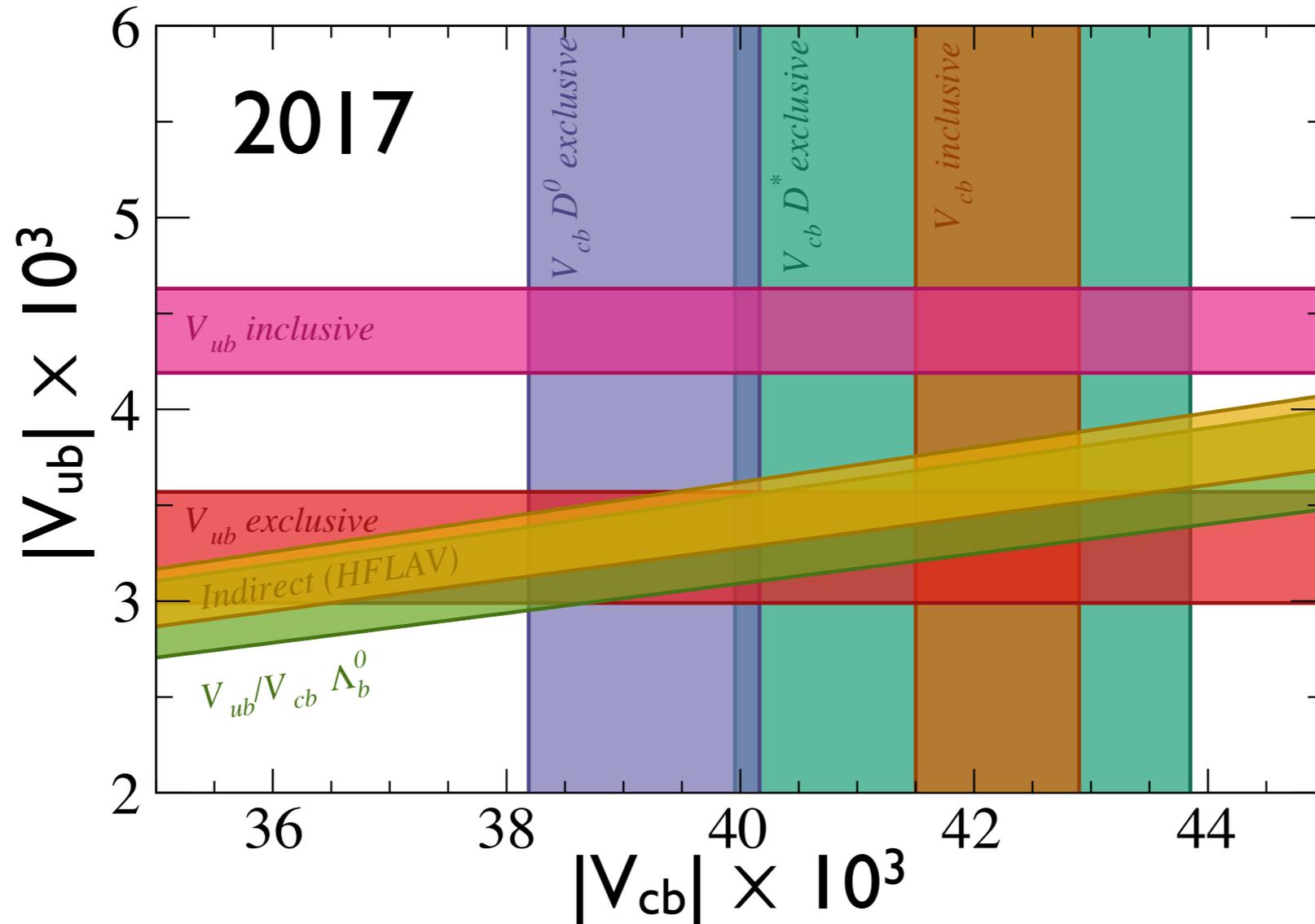




Inclusive-exclusive puzzle



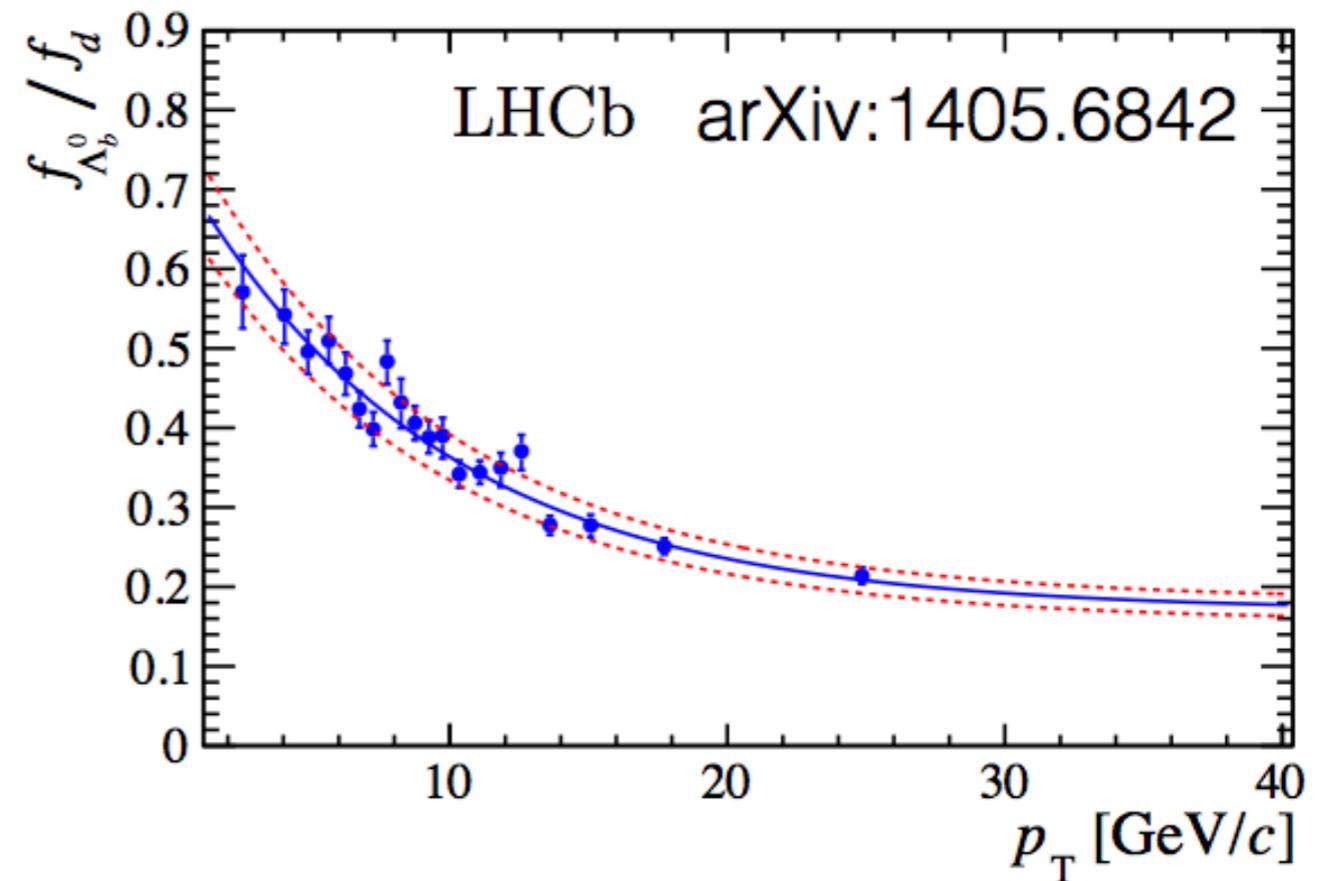
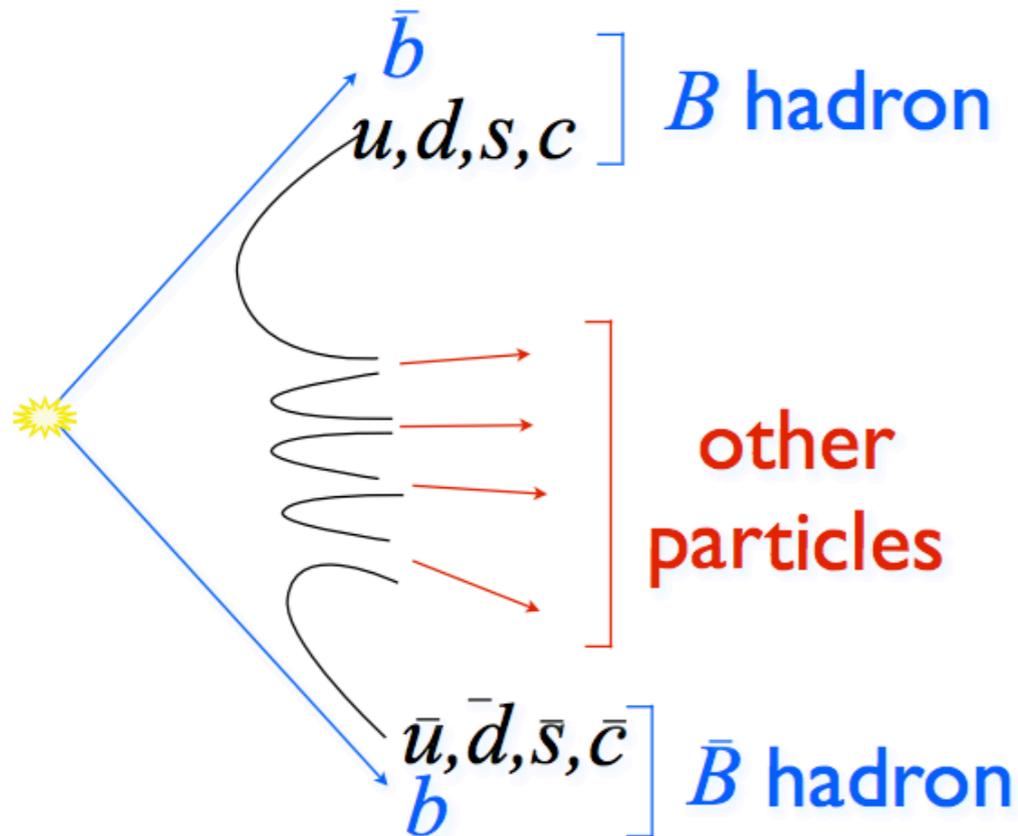
Inclusive-exclusive puzzle



Very recent progress, e.g. Grinstein, Kobach, PLB771 (17) 359-364, Bigi, Gambino, Schacht, PLB 769 (17) 441-445

In any case, it will be invaluable to complement the B meson based measurements with those from other b species.

LHC: access to all b hadrons



We measure product of the b cross section, fragmentation fraction, and branching fractions.

Focus on measurements of ratios or shapes of decay rates.

*Similar arguments apply to CP asymmetries — measure *differences*.

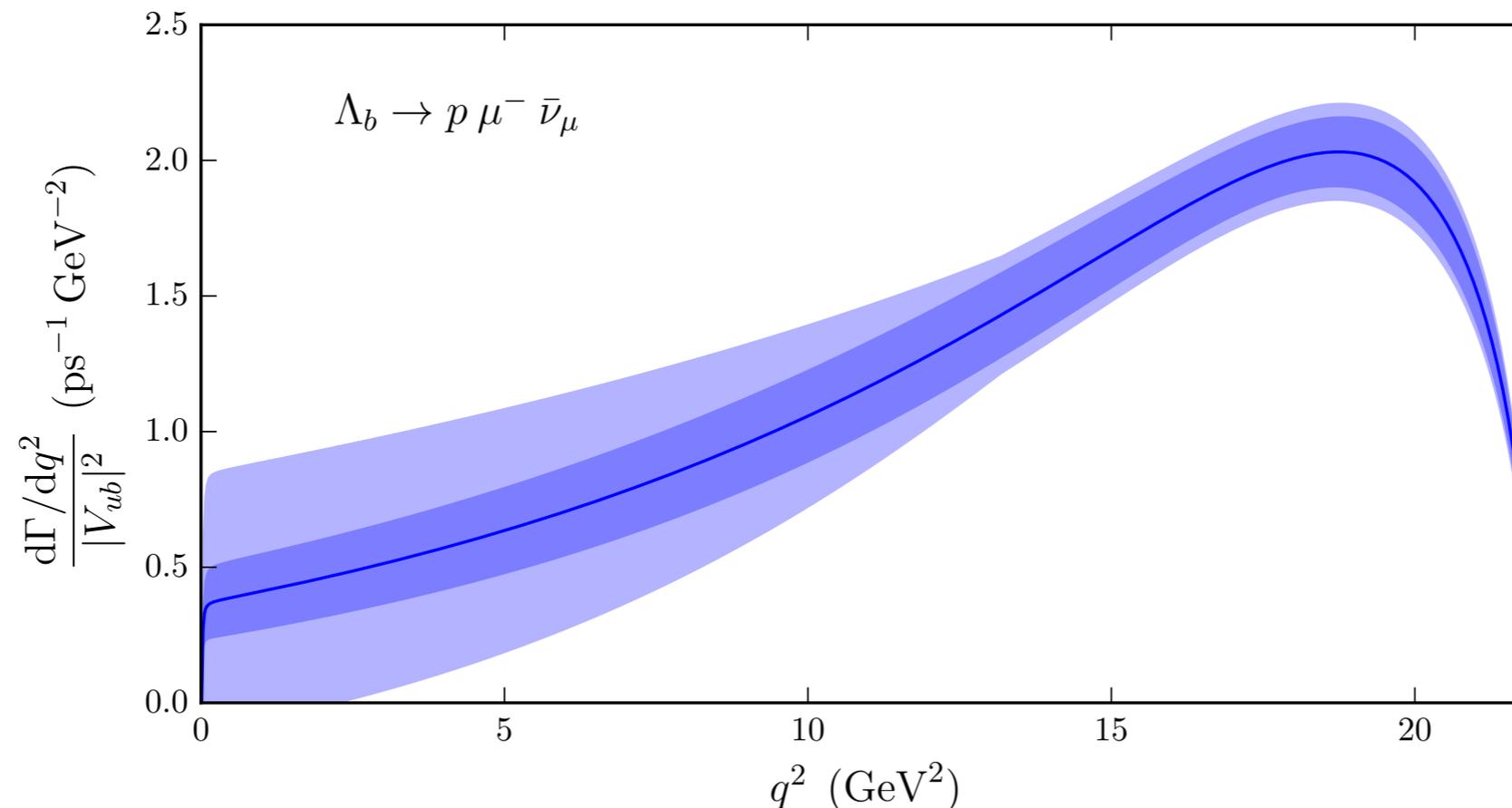
V_{ub} suppressed baryon decay

Measure the ratio

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\mathcal{B}(\Lambda_b^0 \rightarrow p \mu^- \bar{\nu}_\mu)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu)} R_{\text{FF}}$$

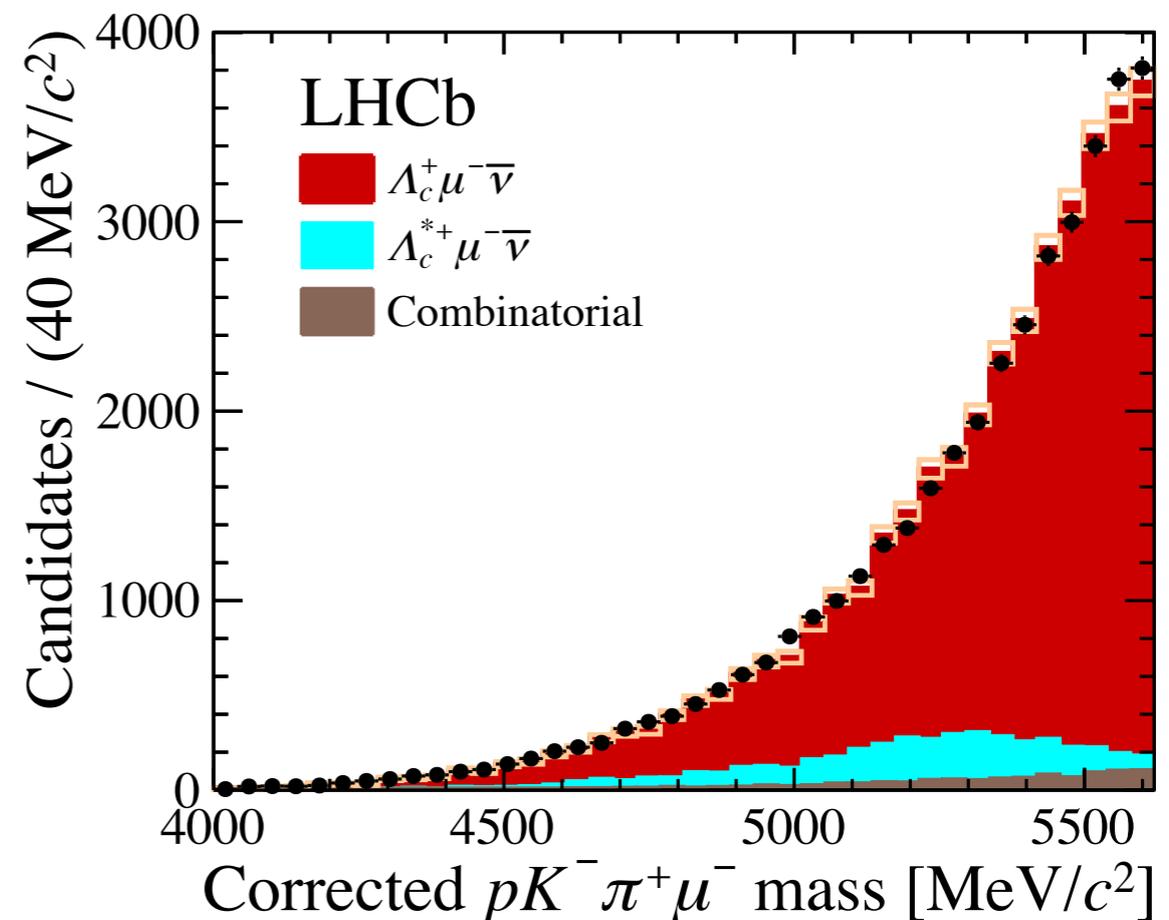
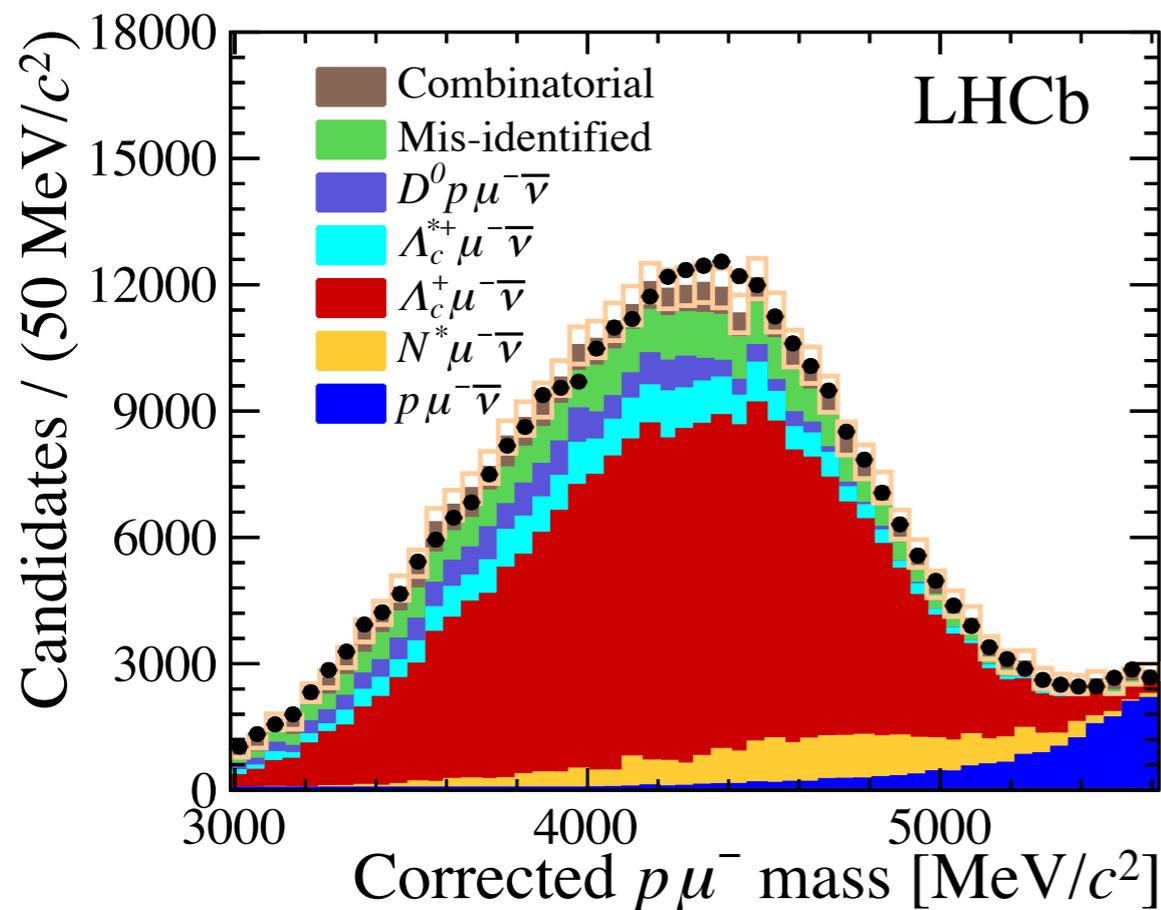
Lattice inputs for R_{FF} , e.g. for the V_{ub} mode:

Detmold, Lehner, Meinel, PRD 92, 034503 (15)



V_{ub} suppressed baryon decay

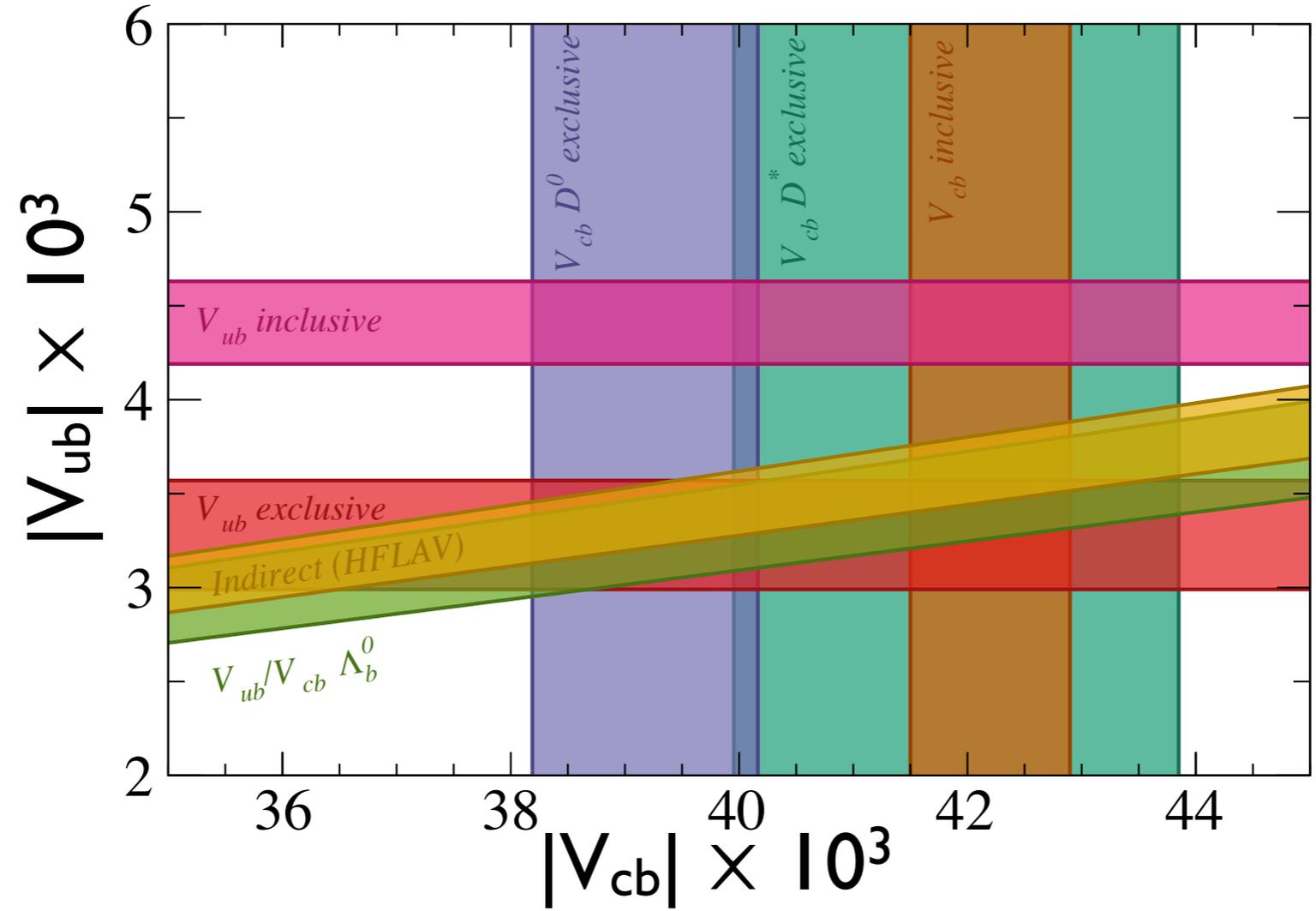
The corrected mass variable exploits the measured flight direction to better resolve the kinematics of the different signals and backgrounds.



$$\frac{\mathcal{B}(\Lambda_b \rightarrow p\mu^- \bar{\nu}_\mu)_{q^2 > 15 \text{ GeV}^2/c^4}}{\mathcal{B}(\Lambda_b \rightarrow \Lambda_c \mu \nu)_{q^2 > 7 \text{ GeV}^2/c^4}} = (1.00 \pm 0.04(\text{stat}) \pm 0.08(\text{syst})) \times 10^{-2}$$

V_{ub} suppressed baryon decay

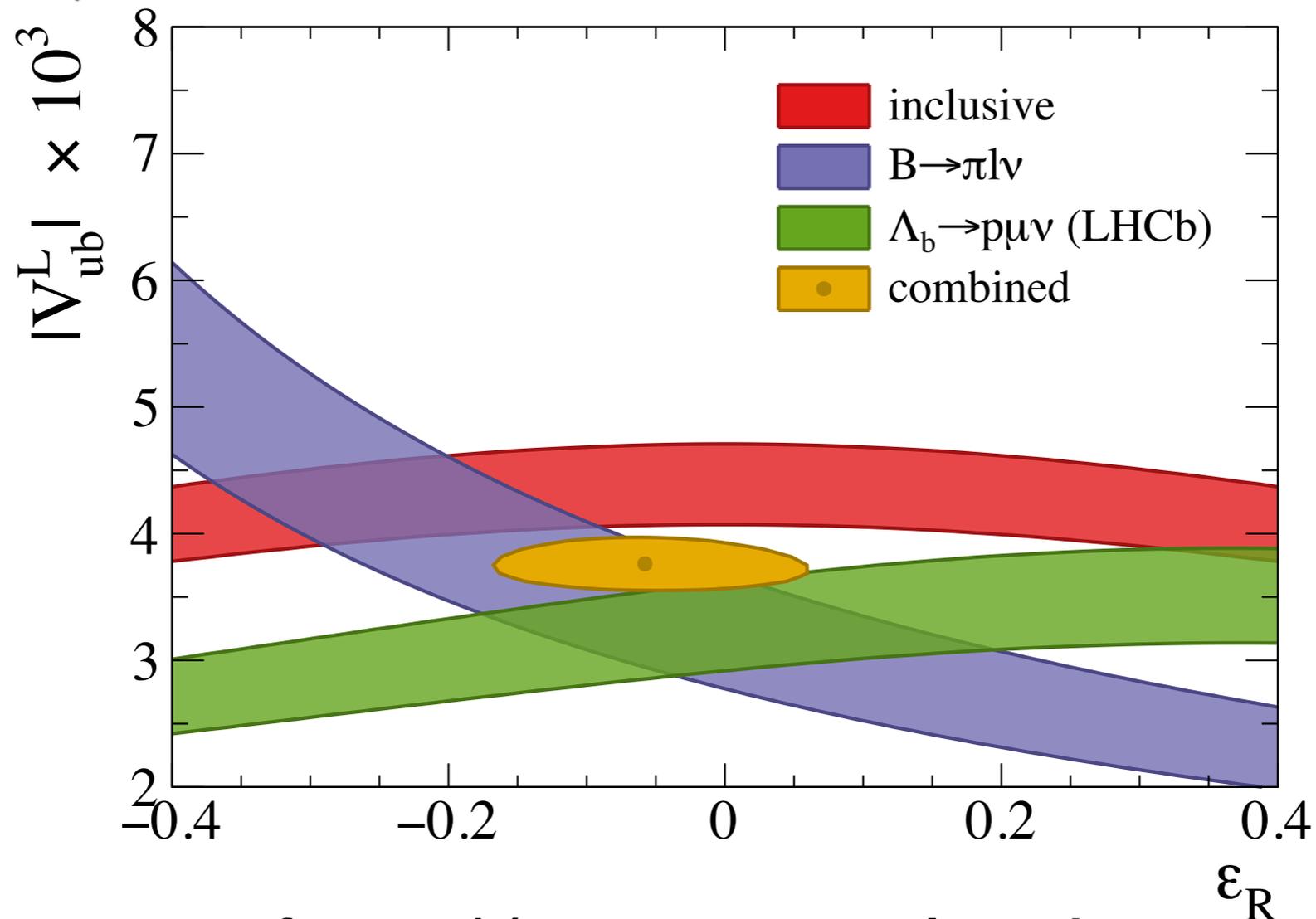
$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004(\text{expt}) \pm 0.004(\text{lattice})$$



Precision already comparable with B meson based exclusive determinations.

V_{ub} suppressed baryon decay

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004(\text{expt}) \pm 0.004(\text{lattice})$$



Complementarity of spin- $1/2$ nature — already very powerful in testing RH-current hypothesis¹ for incl./excl. puzzle.

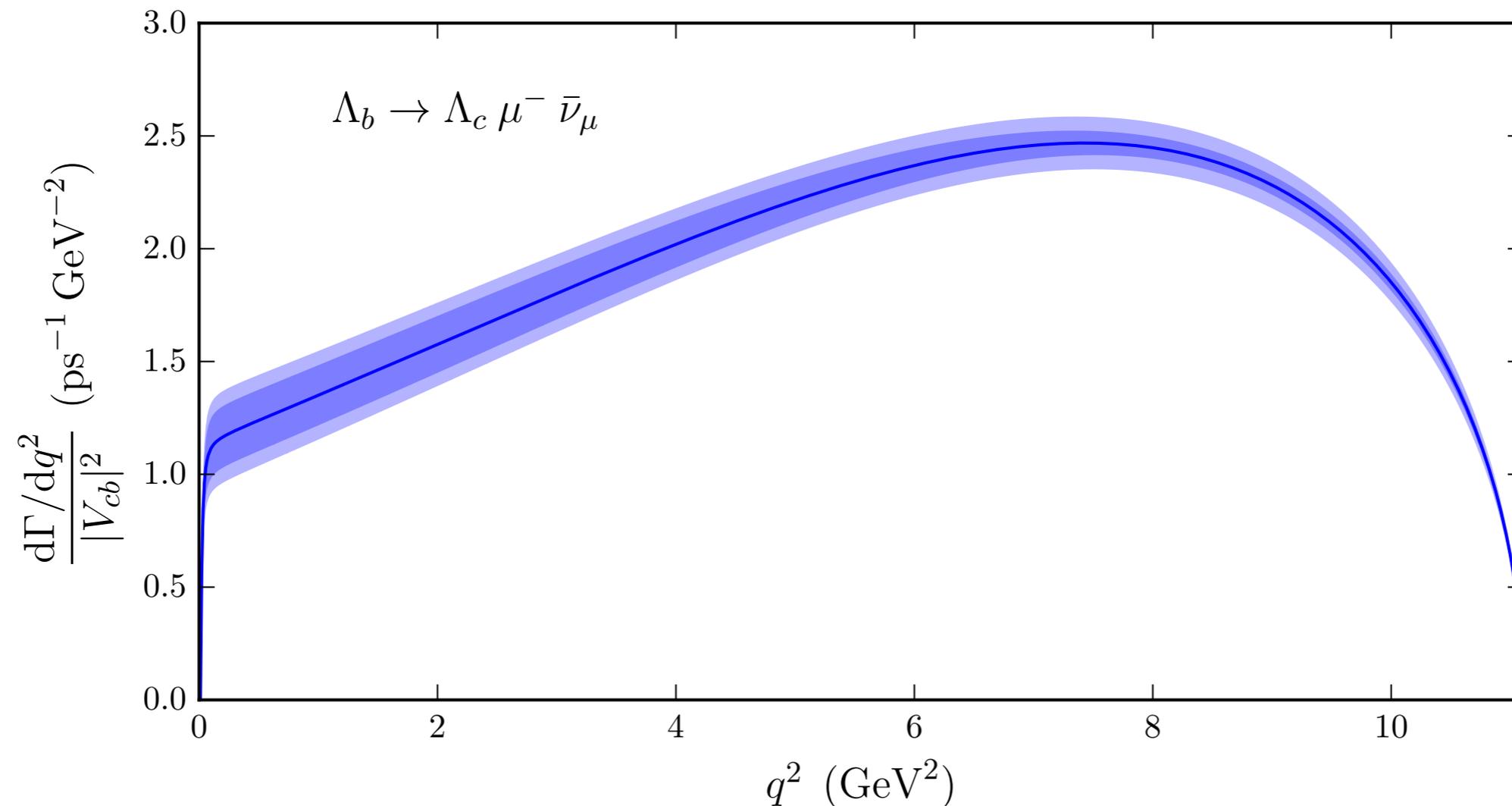
¹ Bernlochner, Ligeti, Turczyk, PRD90 094003 (2014)

V_{ub} suppressed baryon decay

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004(\text{expt}) \pm 0.004(\text{lattice})$$

The lattice predictions for $\Lambda_b \rightarrow \Lambda_c \mu \nu$

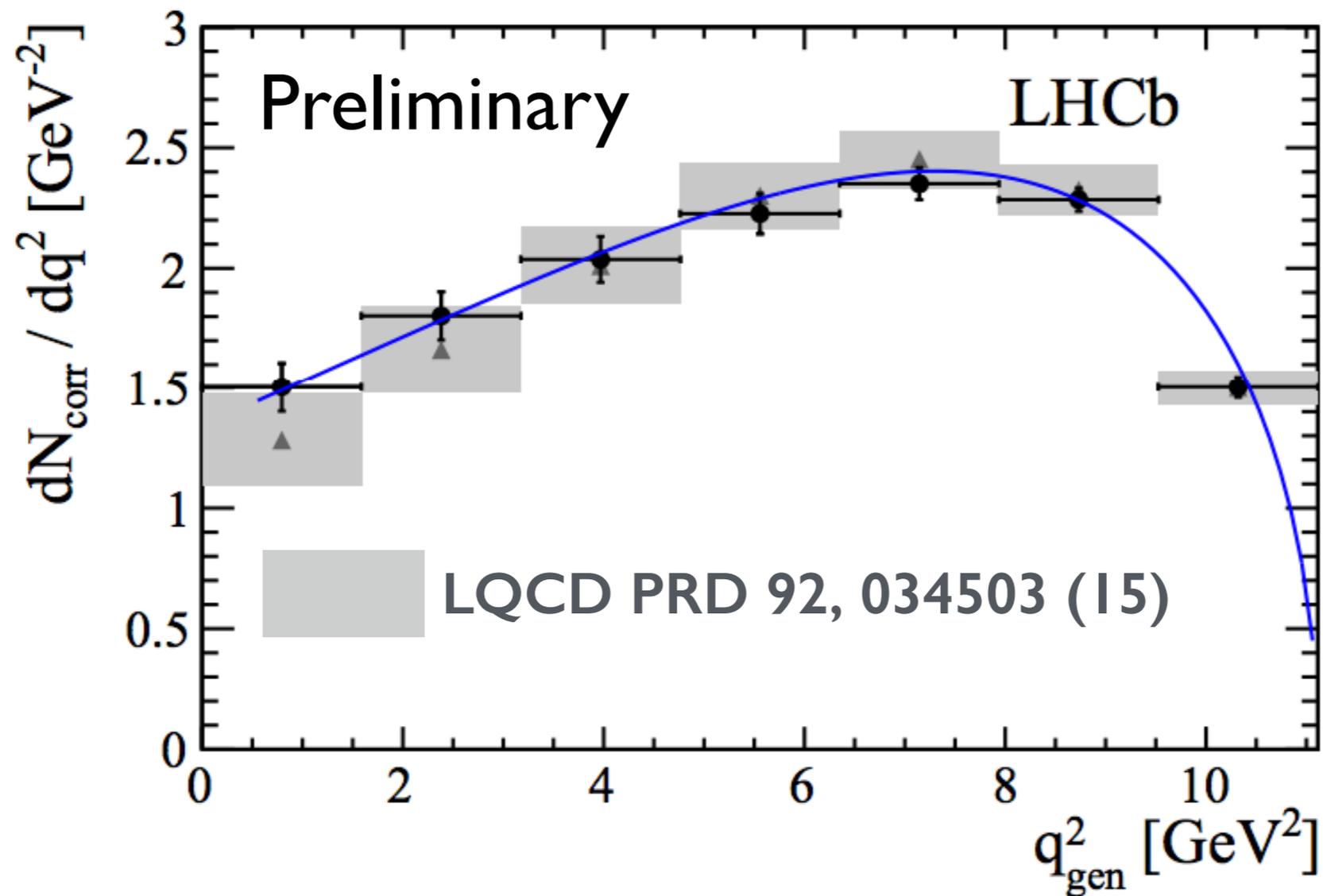
Detmold, Lehner, Meinel, PRD 92, 034503 (15)



NEW

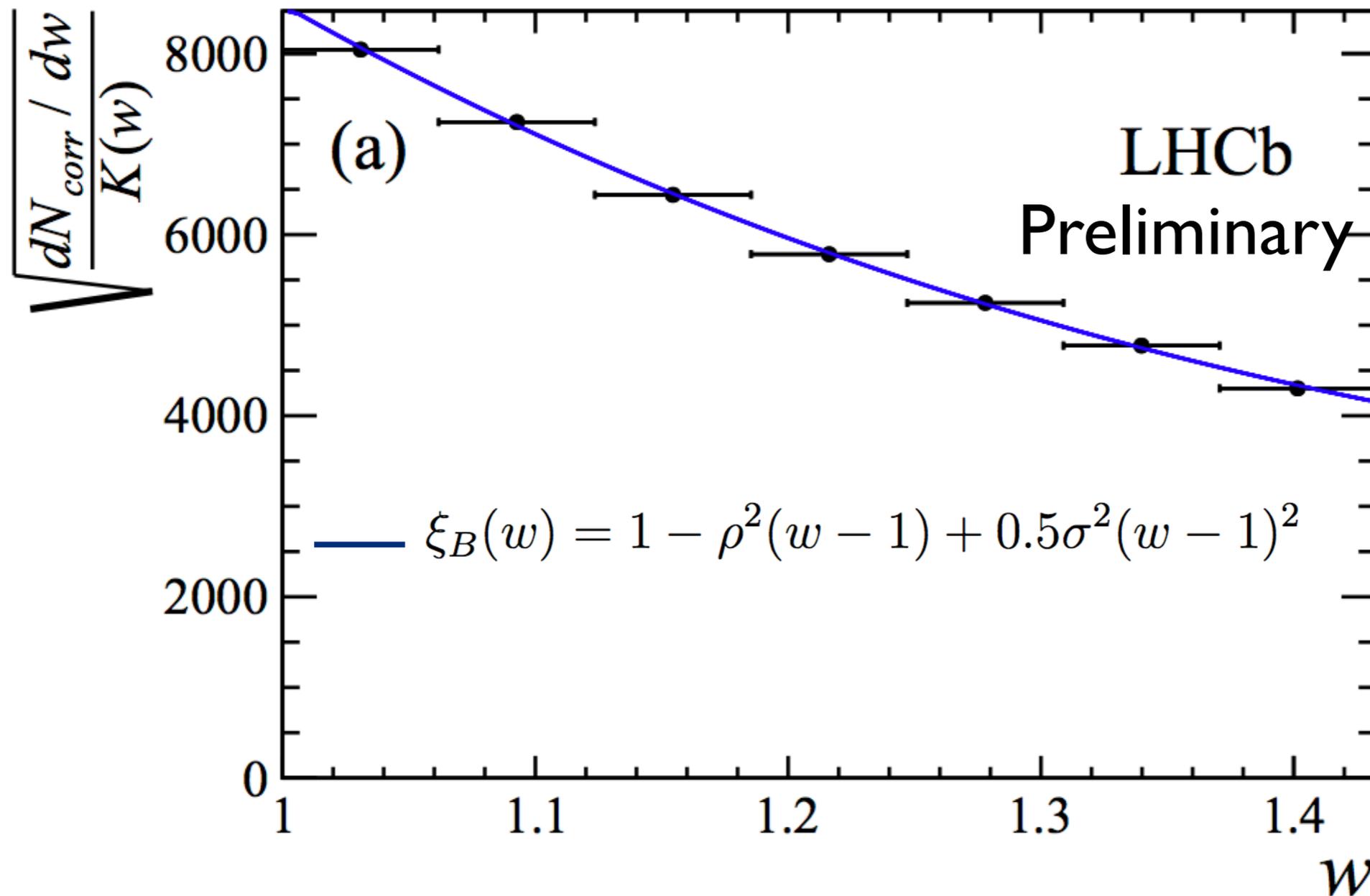
Favoured baryon decay

Measure the *shape* of the $d\Gamma/dq^2$ spectrum of $\Lambda_b \rightarrow \Lambda_c \mu \nu$



NEW

Favoured baryon decay



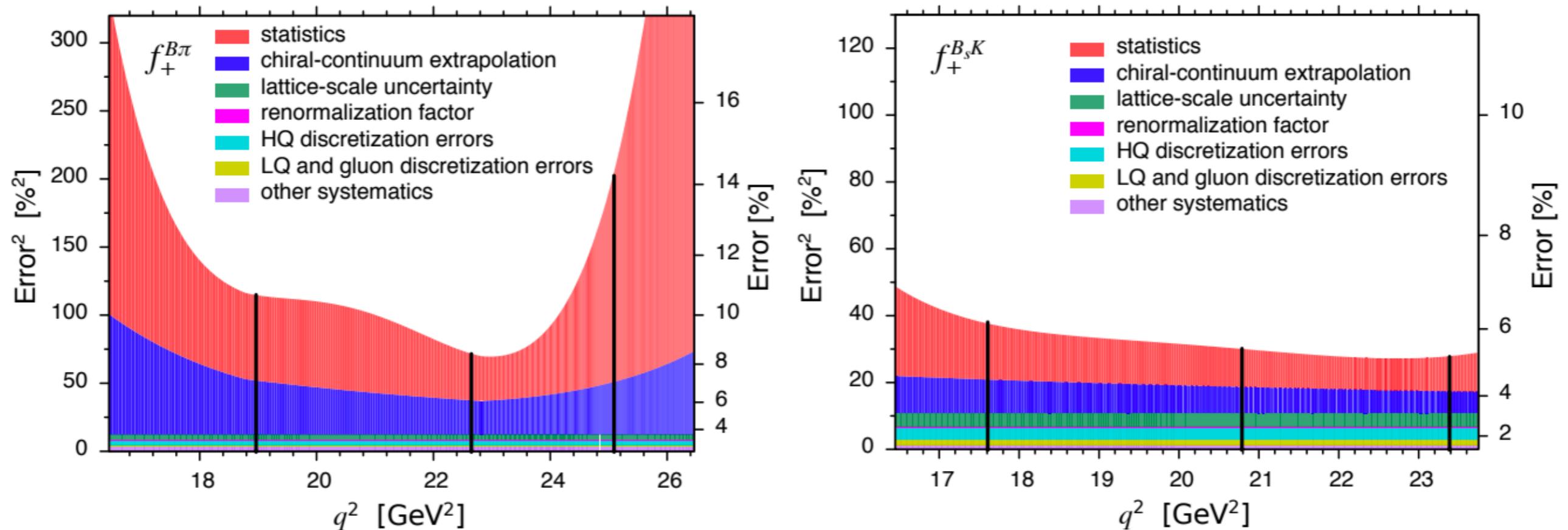
Similar measurements possible with other b species and decay modes!

Prospects with B_s mesons

Great prospects for $|V_{ub}|(/>|V_{cb}|)$ determination with $B_s \rightarrow K\mu\nu$

Same lattice data give $\sim 2x$ better precision than $B \rightarrow \pi\mu\nu$

From: UKQCD/RBC PRD 91, 074510 (15)



Experimentally more challenging than $\Lambda_b \rightarrow p\mu\nu$, but we're working hard on a measurement of $B_s \rightarrow K\mu\nu/B_s \rightarrow D_s\mu\nu$ — Stay tuned!

Prospects with B_s mesons

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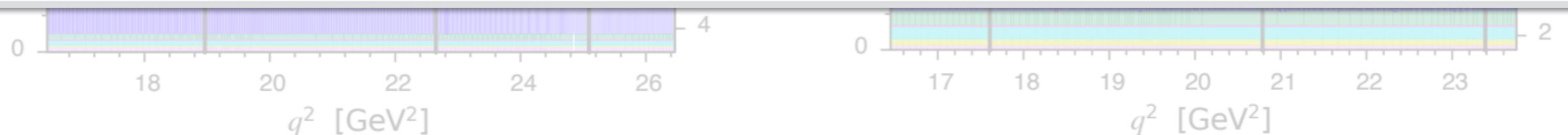
Same lattice data give $\sim 2x$ better precision than $B \rightarrow \pi\mu\nu$

From: UKQCD/RBC PRD 91, 074510 (15)



This is just one example of a rapidly expanding LHCb program with semileptonic b decays.

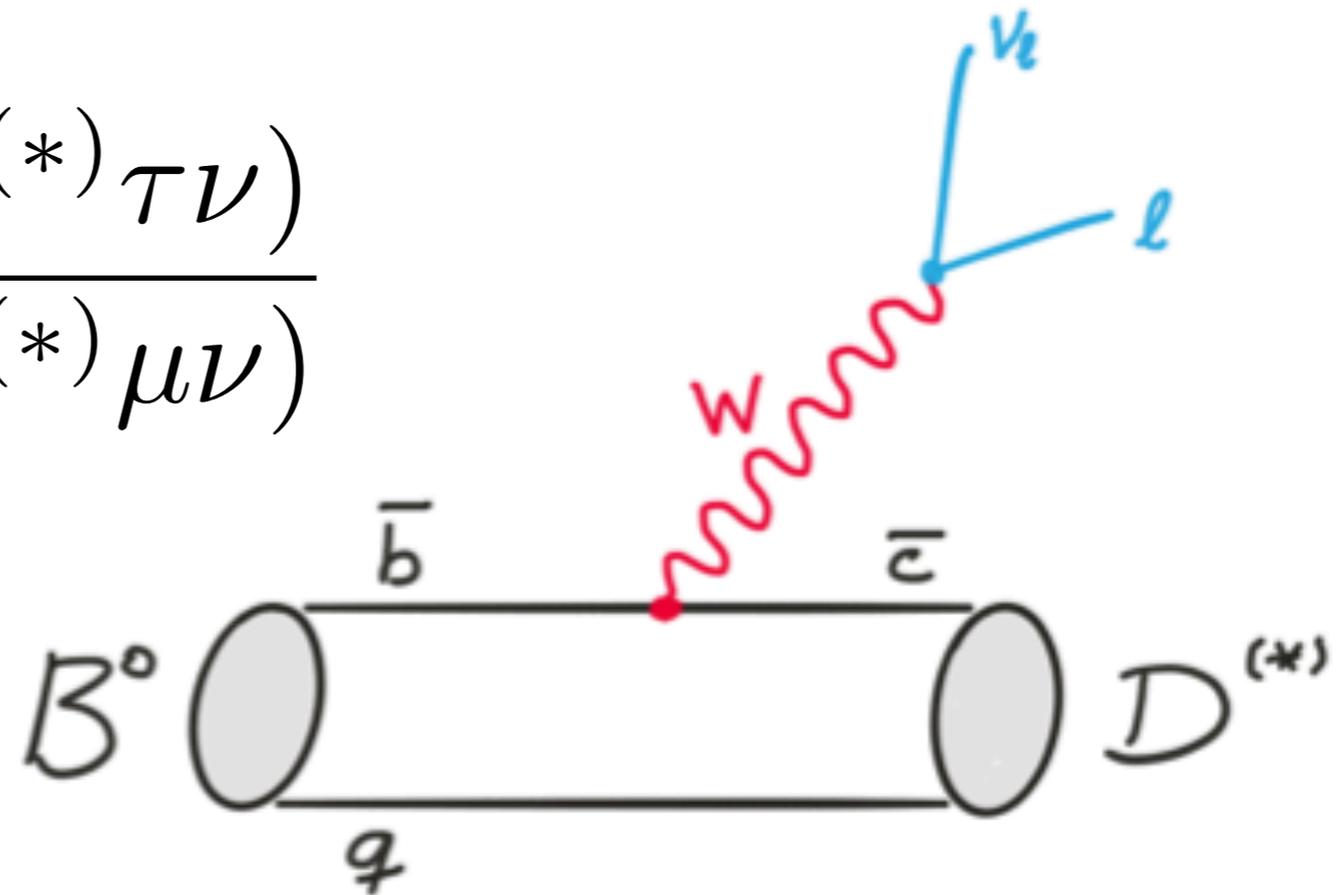
E.g., $B \rightarrow \mu\mu\mu\nu$, $hh\nu$, $\Phi\mu\nu$, $pp\mu\nu$, various B_s , B_c , etc...



Experimentally more challenging than $\Lambda_b \rightarrow p\mu\nu$, but we're working hard on a measurement of $B_s \rightarrow K\mu\nu/B_s \rightarrow D_s\mu\nu$ — Stay tuned!

Tree LFU tests

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu)}{\mathcal{B}(B \rightarrow D^{(*)} \mu \nu)}$$



SM predictions:

$$R(D) = 0.300 \pm 0.008$$

$$R(D^*) = 0.252 \pm 0.003$$

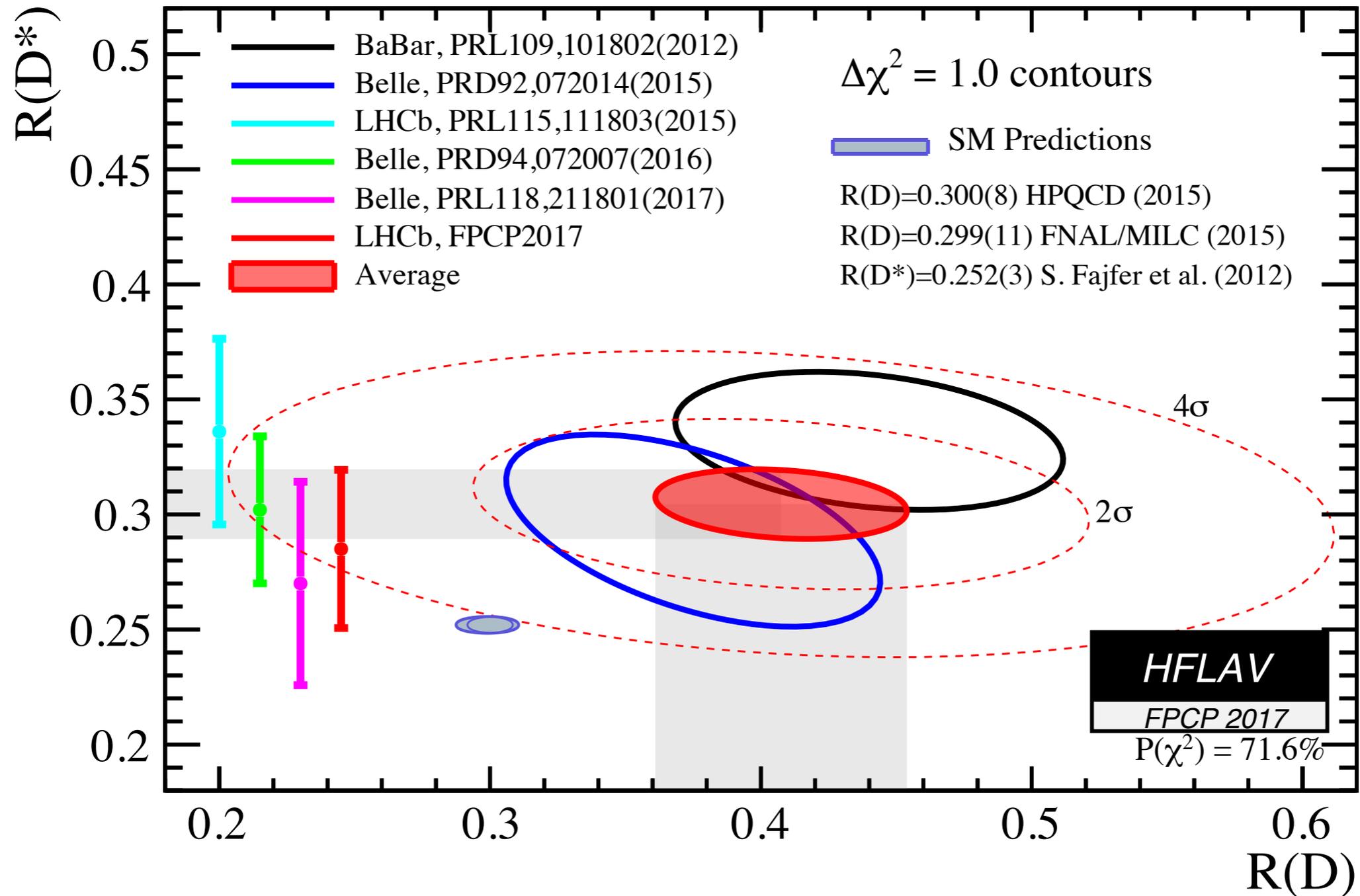
Fajfer, Kamenik, Nisandzic, PRD85 (12) 094025
Bigi, Gambino, PRD94 (16)

(Very precise and well scrutinised/
trusted by the community)

Experiment:

$$R(D^*) \rightarrow 6\% \text{ precision}$$

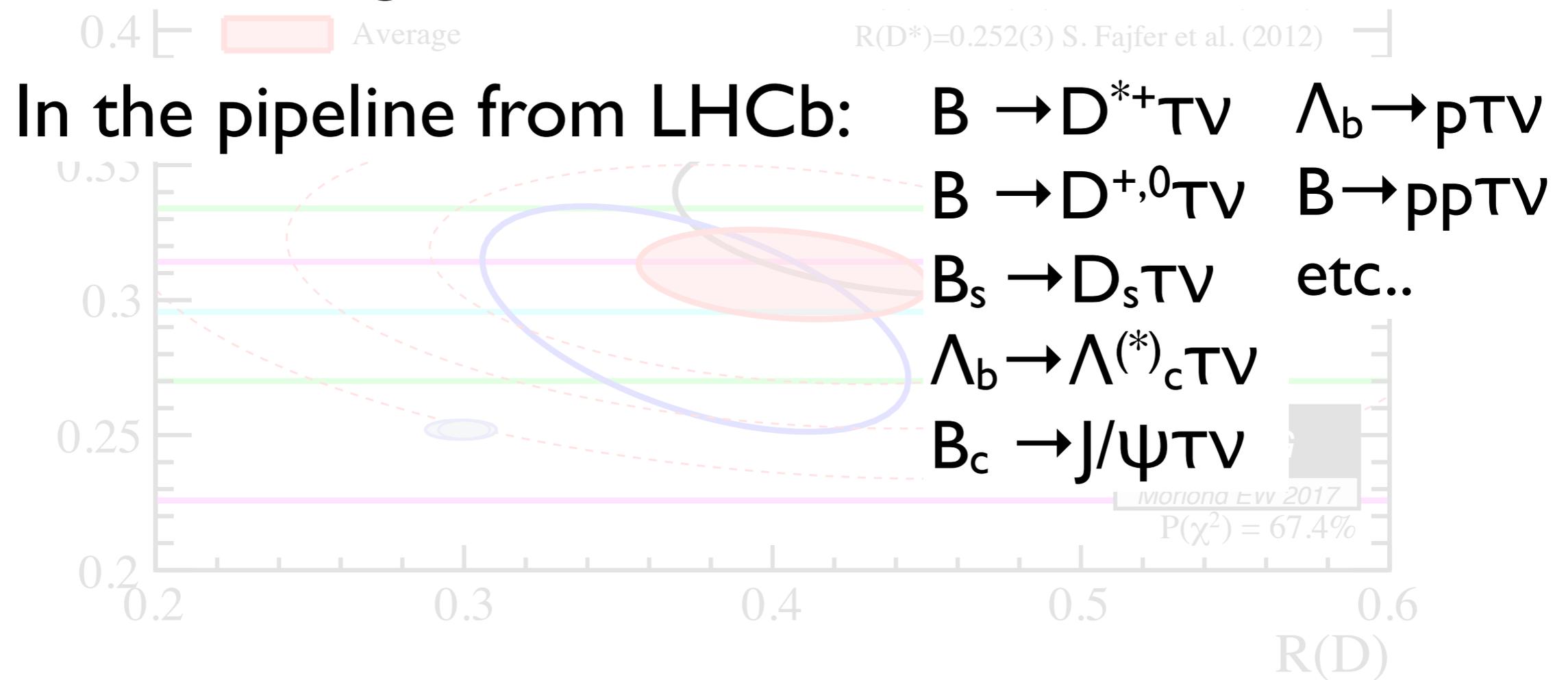
Tree LFU tests



Combined $R(D, D^*)$ is now $\sim 4\sigma$ from SM

Tree LFU tests

* If this is due to BSM physics, two observables aren't enough to characterise it.



Tree LFU tests

If this is due to BSM physics, two observables aren't enough to characterise it.

In the pipeline from LHCb:



etc..



For now:

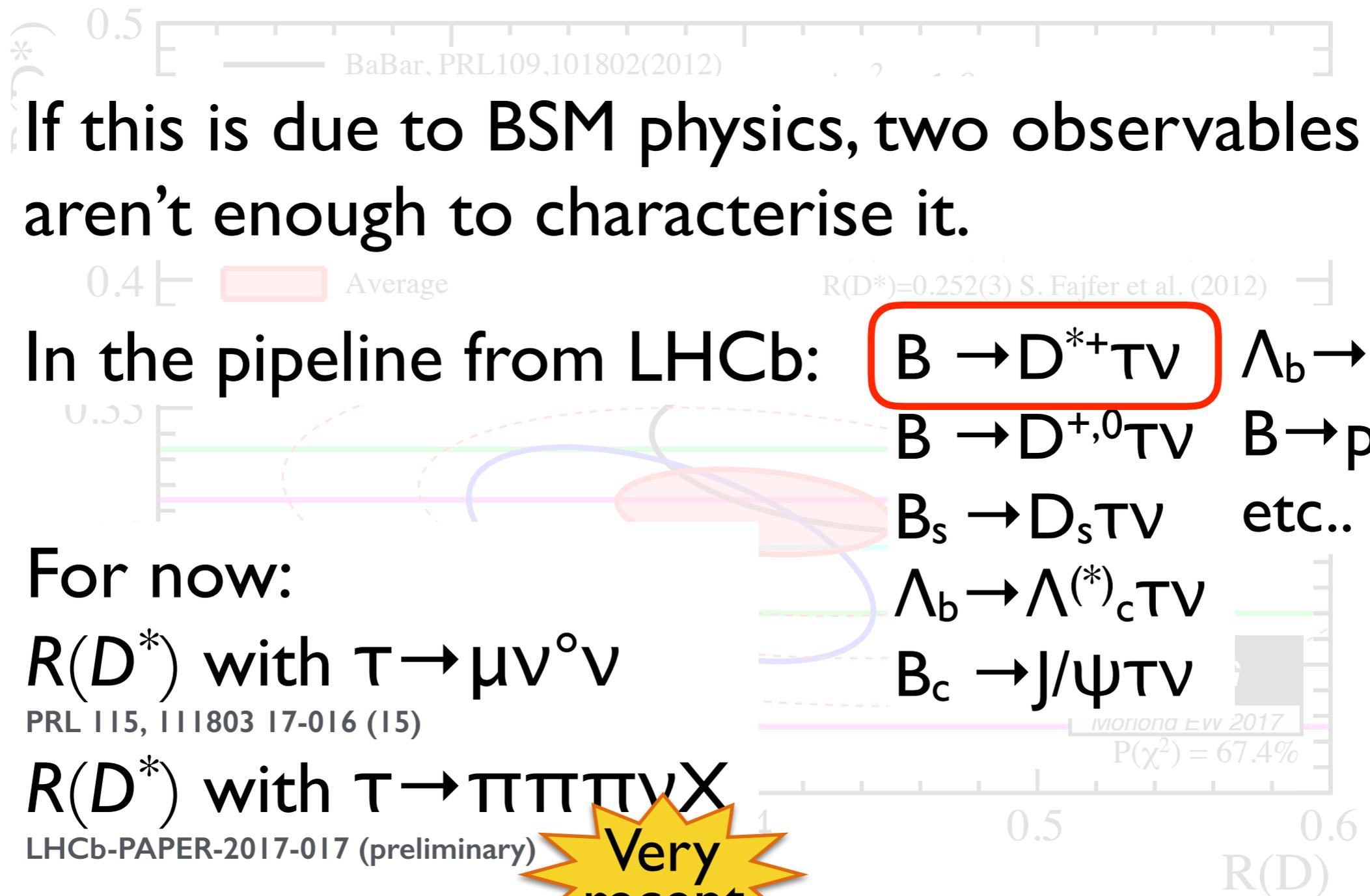
$R(D^*)$ with $\tau \rightarrow \mu \nu^o \nu$

PRL 115, 111803 17-016 (15)

$R(D^*)$ with $\tau \rightarrow \pi \pi \pi \nu X$

LHCb-PAPER-2017-017 (preliminary)

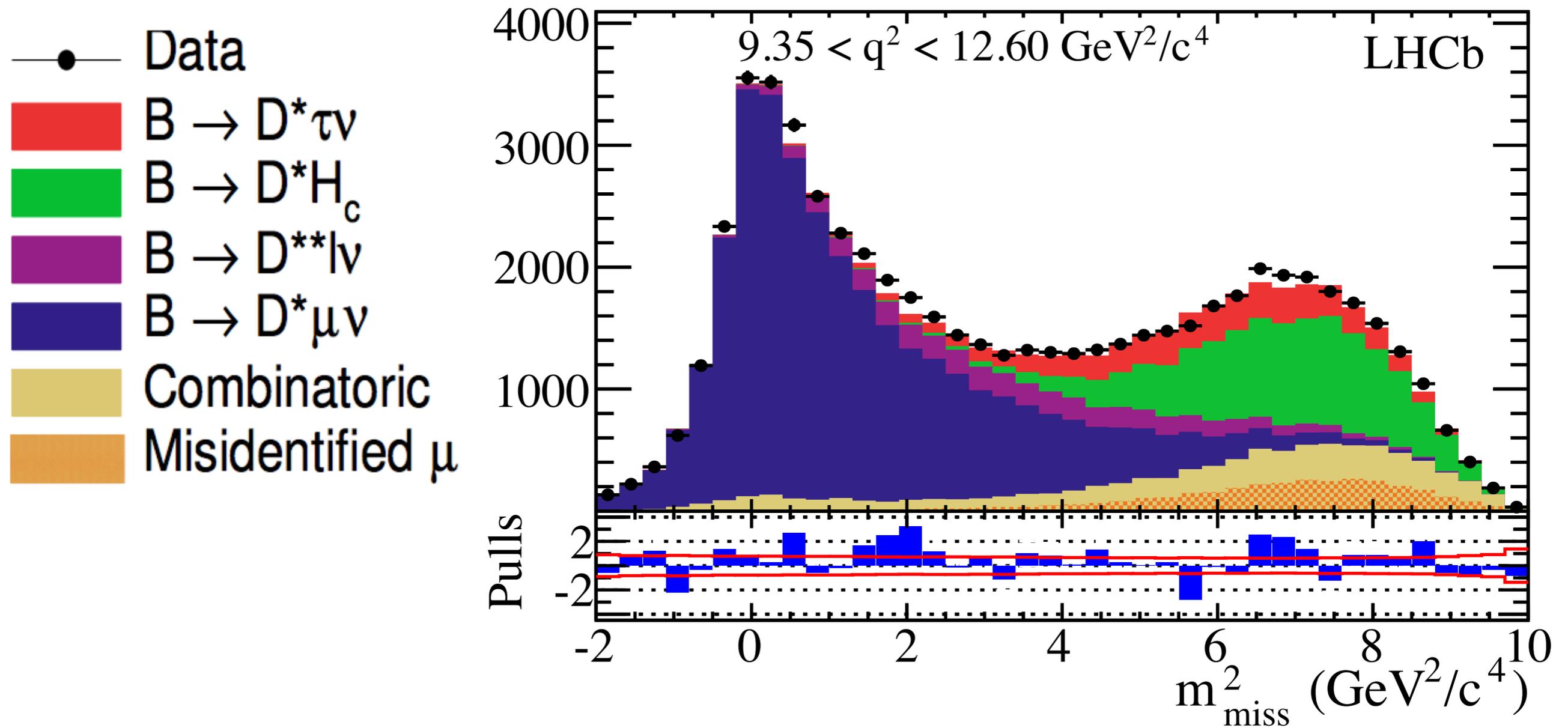
Very recent



LHCb muonic $R(D^*)$

Fit in bins of q^2 , m_{miss}^2 , and E_μ .

Here is the m_{miss}^2 projection in the highest purity q^2 bin:



LHCb hadronic $R(D^*)$

We actually measure
$$\frac{\mathcal{B}(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{\mathcal{B}(B^0 \rightarrow D^{*-} 3\pi)}$$

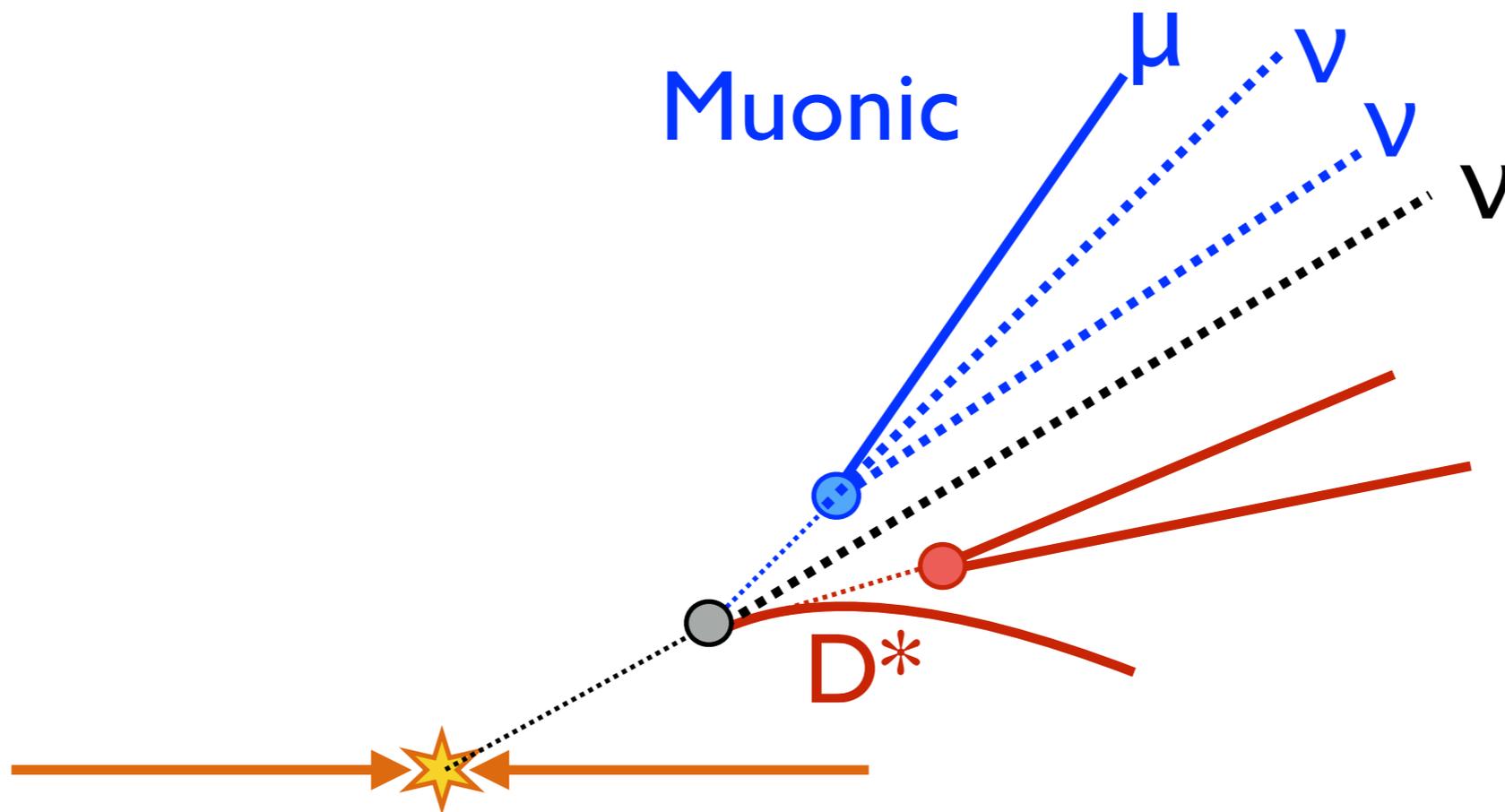
And use external measurements of $\mathcal{B}(B \rightarrow D^* 3\pi)$ and $\mathcal{B}(B \rightarrow D^* \mu \nu)$ to get $R(D^*)$.

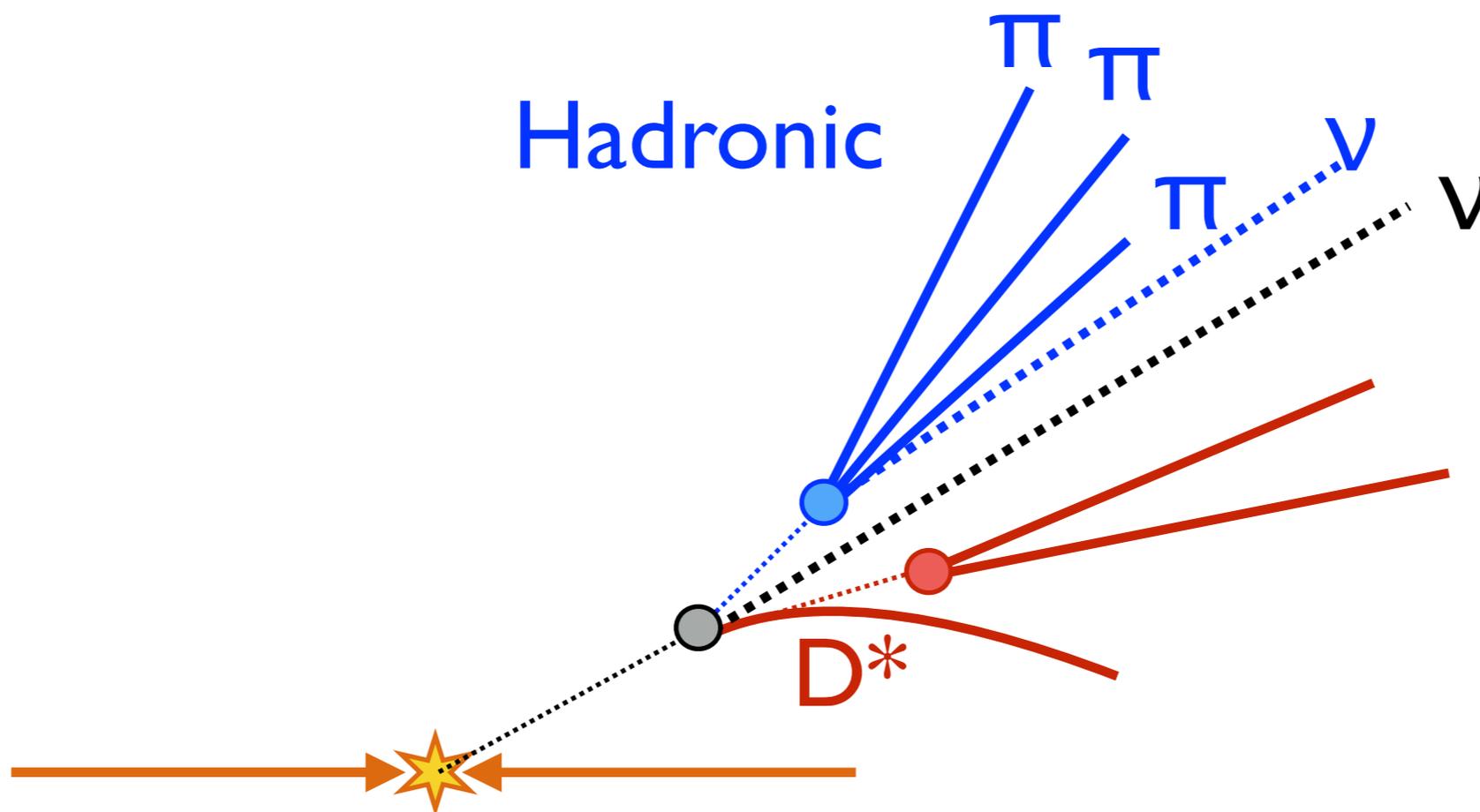
This required a new (2016) measurement of $\mathcal{B}(B \rightarrow D^* 3\pi)$ from BaBar. PRD 94 091101 (2016)

$$\mathcal{B}(B \rightarrow D^* 3\pi) = (0.726 \pm 0.011 \pm 0.031) \times 10^{-2}$$

RECENT

LHCb hadronic $R(D^*)$

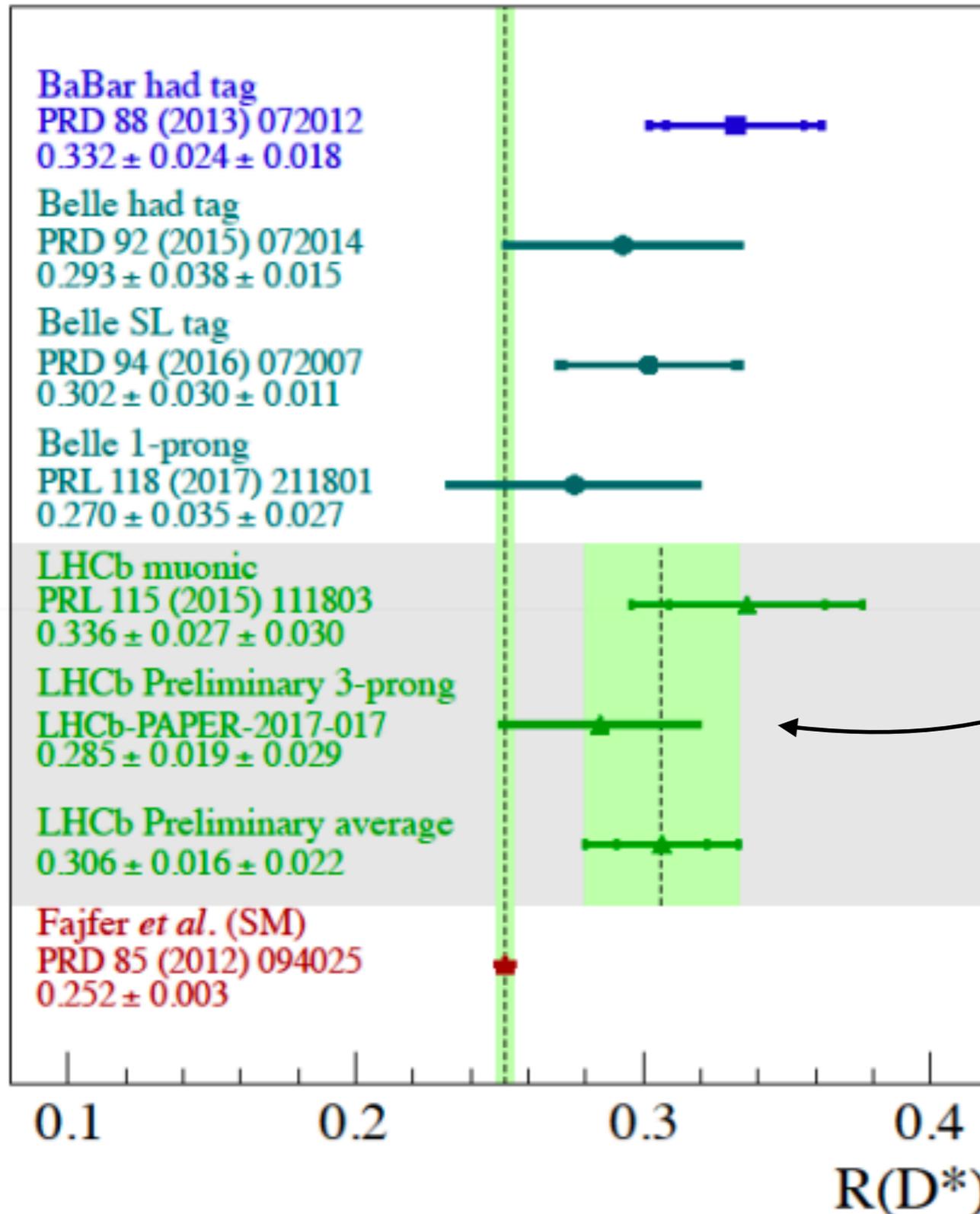


LHCb hadronic $R(D^*)$ 

Different challenges, but expect the better constrained kinematics to allow very higher purity...

RECENT

LHCb hadronic $R(D^*)$

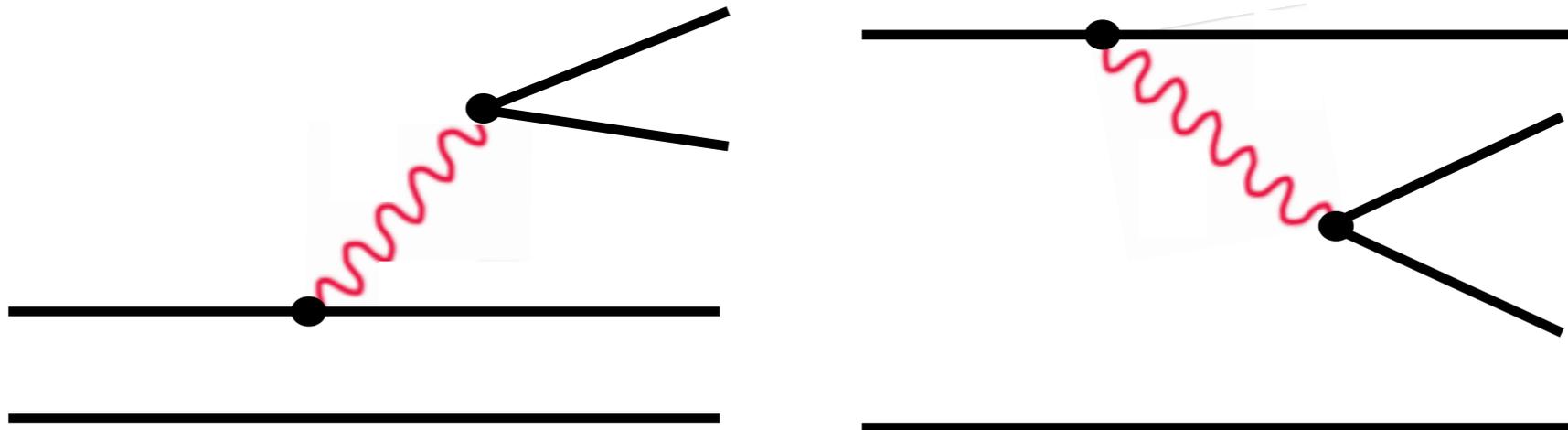


First measurement with this decay mode!

And look forward to:

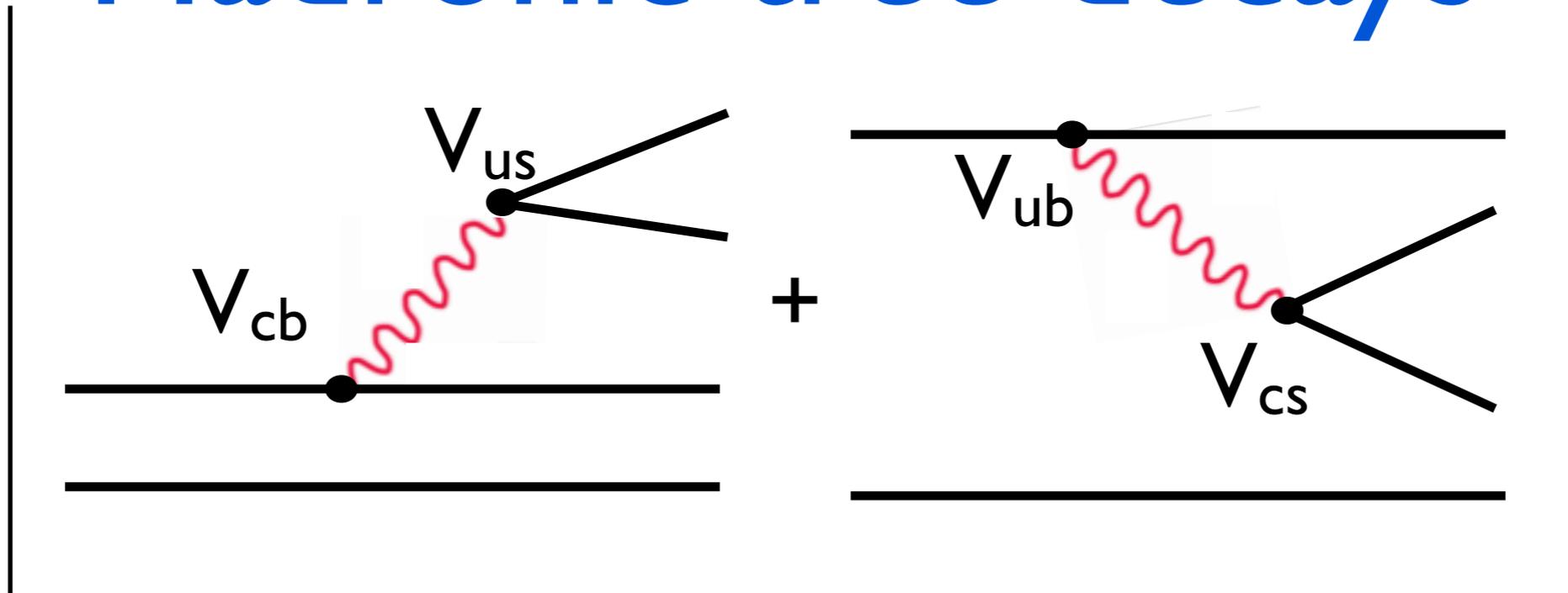
$R(D^{*+})$, $R(D^{+,0})$, $R(D_s^{(*)})$,
 $R(\Lambda_c^{(*)})$, $R(J/\psi)$,
 $R(pp)$, $R(p)$, etc...

Hadronic tree decays



Hadronic tree decays

2



E.g. if the D^0 decays to a CP eigenstate, these two interfere.

leads to a CP-violating asymmetry that depends on; the amplitude ratio, and relative weak (γ) and strong phases.

Various methods with different decays. E.g. GLW (above example), ADS, GLS, GGSZ.

NEW

LHCb γ combination

| <i>B</i> decay | <i>D</i> decay | Method | Ref. | Status since last combination [1] |
|------------------------------------|------------------------------------|------------|------|-----------------------------------|
| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+h^-$ | GLW | [2] | Updated to Run 2 |
| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+h^-$ | ADS | [19] | As before |
| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+\pi^-\pi^+\pi^-$ | GLW/ADS | [19] | As before |
| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+h^-\pi^0$ | GLW/ADS | [20] | As before |
| $B^+ \rightarrow DK^+$ | $D \rightarrow K_s^0 h^+ h^-$ | GGSZ | [21] | As before |
| $B^+ \rightarrow DK^+$ | $D \rightarrow K_s^0 K^+ \pi^-$ | GLS | [22] | As before |
| $B^+ \rightarrow D^* K^+$ | $D \rightarrow h^+ h^-$ | GLW | [2] | New |
| $B^+ \rightarrow DK^{*+}$ | $D \rightarrow h^+ h^-$ | GLW/ADS | [3] | New |
| $B^+ \rightarrow DK^+ \pi^+ \pi^-$ | $D \rightarrow h^+ h^-$ | GLW/ADS | [23] | As before |
| $B^0 \rightarrow DK^{*0}$ | $D \rightarrow K^+ \pi^-$ | ADS | [24] | As before |
| $B^0 \rightarrow DK^+ \pi^-$ | $D \rightarrow h^+ h^-$ | GLW-Dalitz | [25] | As before |
| $B^0 \rightarrow DK^{*0}$ | $D \rightarrow K_s^0 \pi^+ \pi^-$ | GGSZ | [26] | As before |
| $B_s^0 \rightarrow D_s^\mp K^\pm$ | $D_s^+ \rightarrow h^+ h^- \pi^+$ | TD | [4] | Updated to 3 fb^{-1} |

NEW

LHCb-CONF-2017-004
(in preparation)

LHCb γ combination

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| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+\pi^-\pi^+\pi^-$ | GLW/ADS | [19] | As before |

W.r.t. JHEP 12 (2016) 087

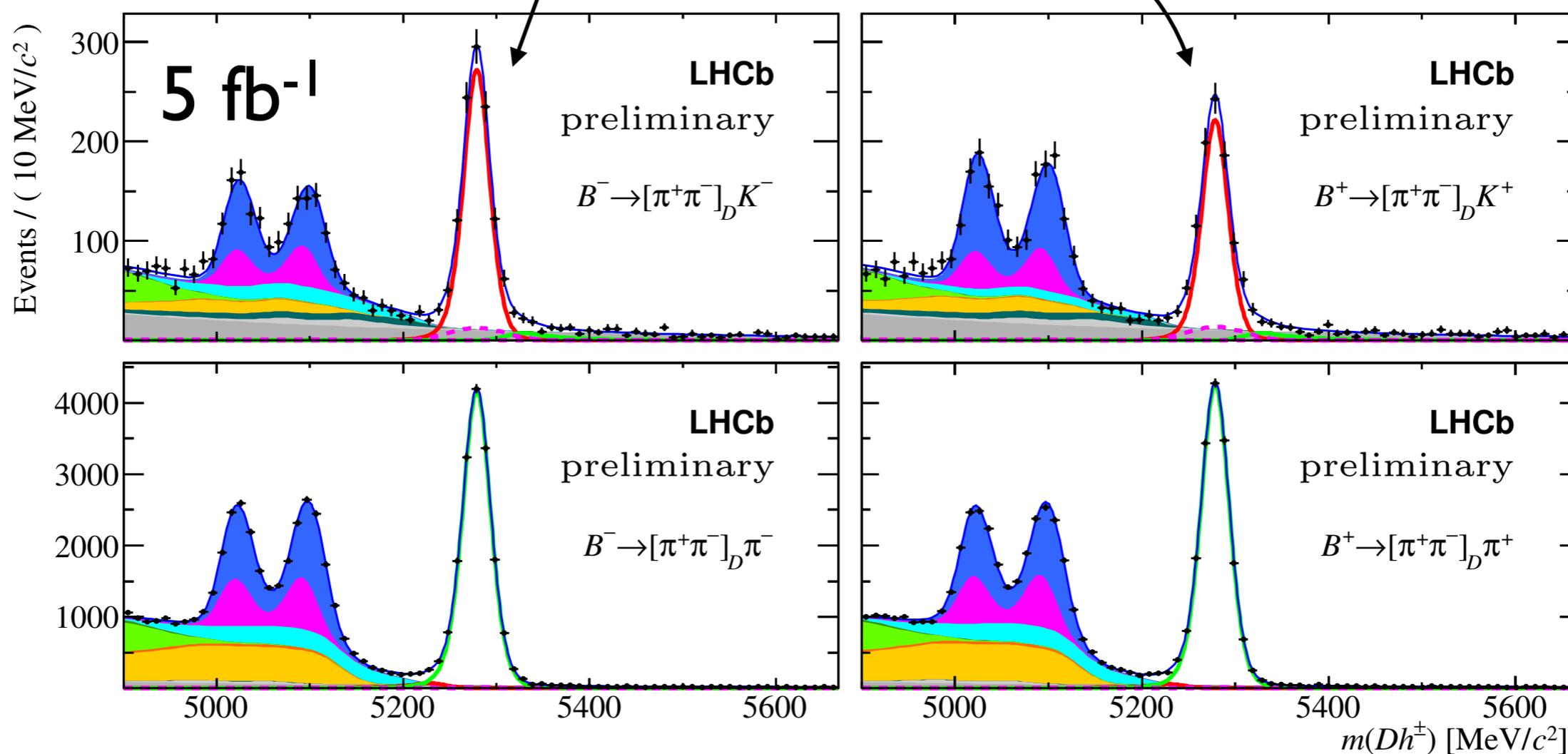
| | | | |
|-----------------------------------|---------------------------------|---------|-------------------------------|
| $B^+ \rightarrow DK^+$ | $D \rightarrow h^+h^-$ | GLW | Updated to Run 2 |
| $B_s^0 \rightarrow D_s^\mp K^\pm$ | $D_s^+ \rightarrow h^+h^-\pi^+$ | TD | Updated to 3 fb ⁻¹ |
| $B^+ \rightarrow D^*K^+$ | $D \rightarrow h^+h^-$ | GLW | New |
| $B^+ \rightarrow DK^{*+}$ | $D \rightarrow h^+h^-$ | GLW/ADS | New |

| | | | |
|-----------------------------------|---------------------------------|------------|-----------------------------------|
| $B^0 \rightarrow DK^+\pi^-$ | $D \rightarrow h^+h^-$ | GLW-Dalitz | [25] As before |
| $B^0 \rightarrow DK^{*0}$ | $D \rightarrow K_s^0\pi^+\pi^-$ | GGSZ | [26] As before |
| $B_s^0 \rightarrow D_s^\mp K^\pm$ | $D_s^+ \rightarrow h^+h^-\pi^+$ | TD | [4] Updated to 3 fb ⁻¹ |

NEW

Example new mode

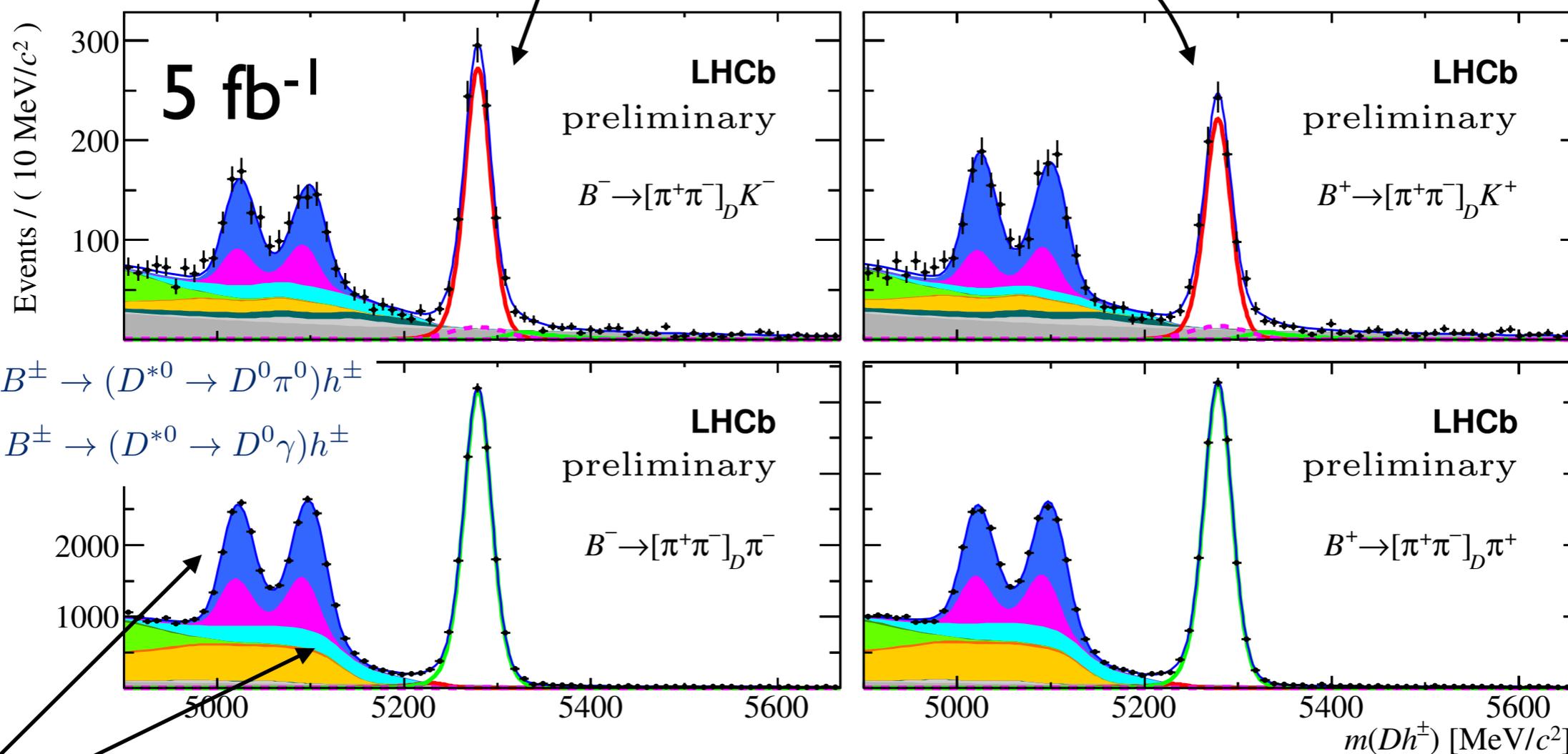
CP asymmetries of main $B \rightarrow D^0 h$ peaks are related to γ in well known GLW method.



NEW

Example new mode

CP asymmetries of main $B \rightarrow D^0 h$ peaks are related to γ in well known GLW method.

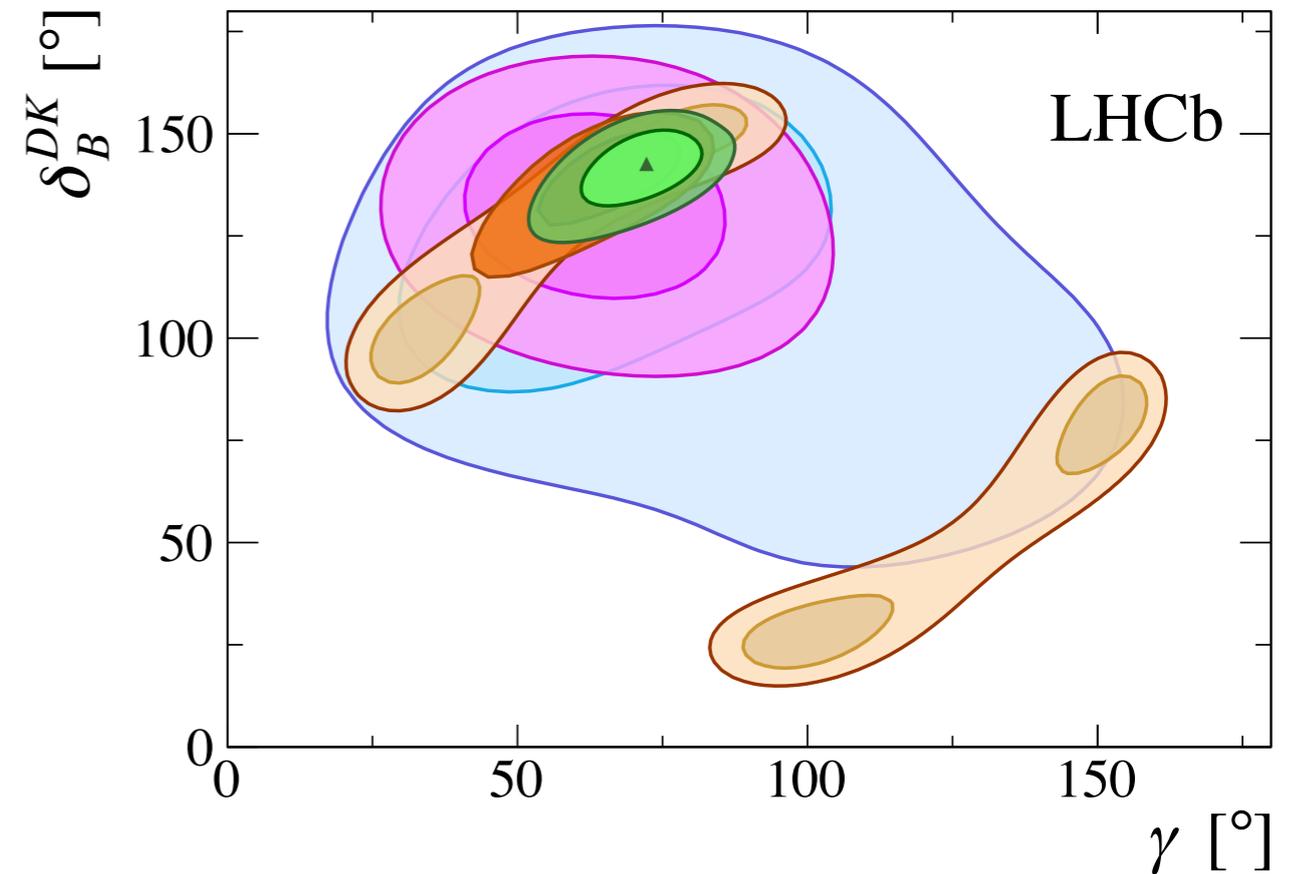
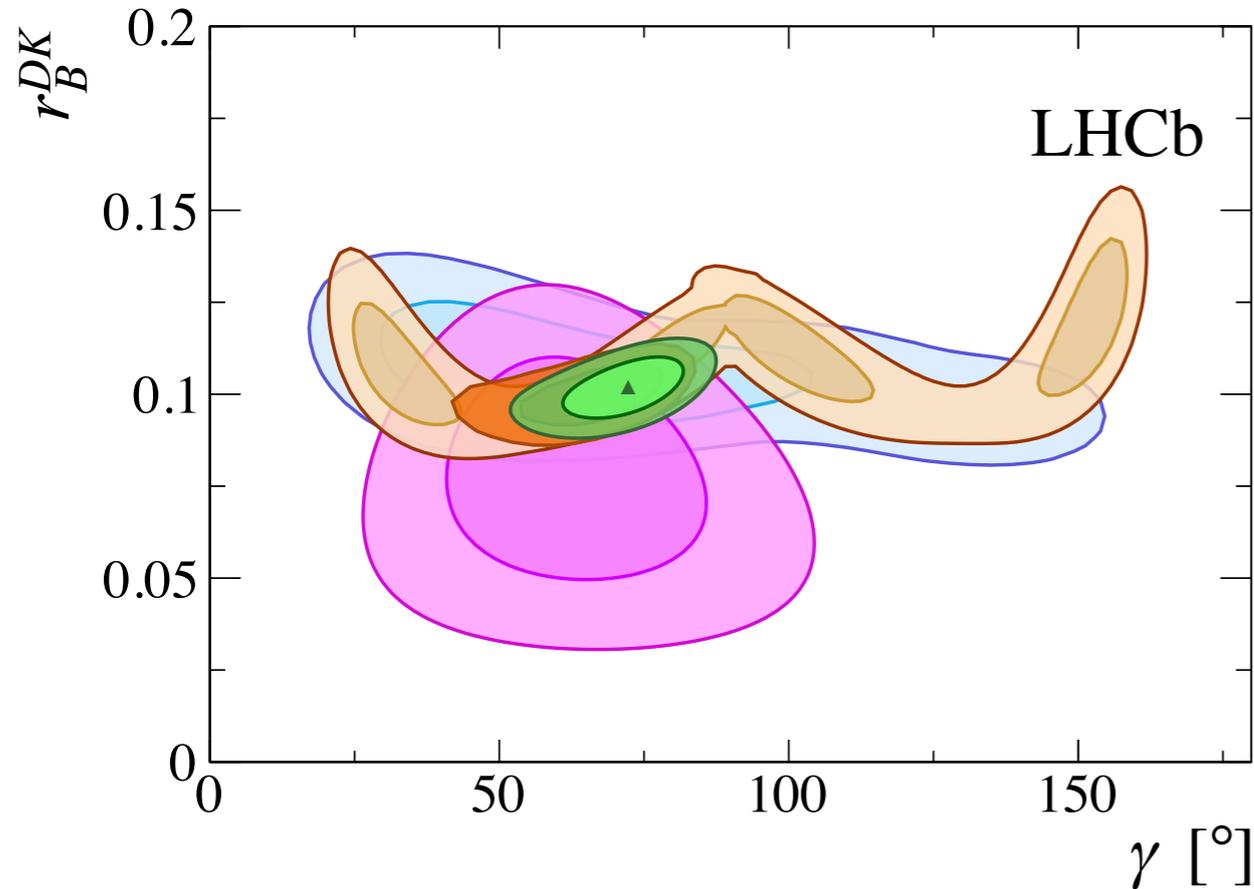


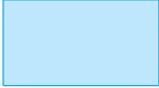
Can measure $B \rightarrow D^* h$ equivalents without actually reconstructing the full D^* decays!



LHCb γ combination

Nov 2016 JHEP 12 (16) 087

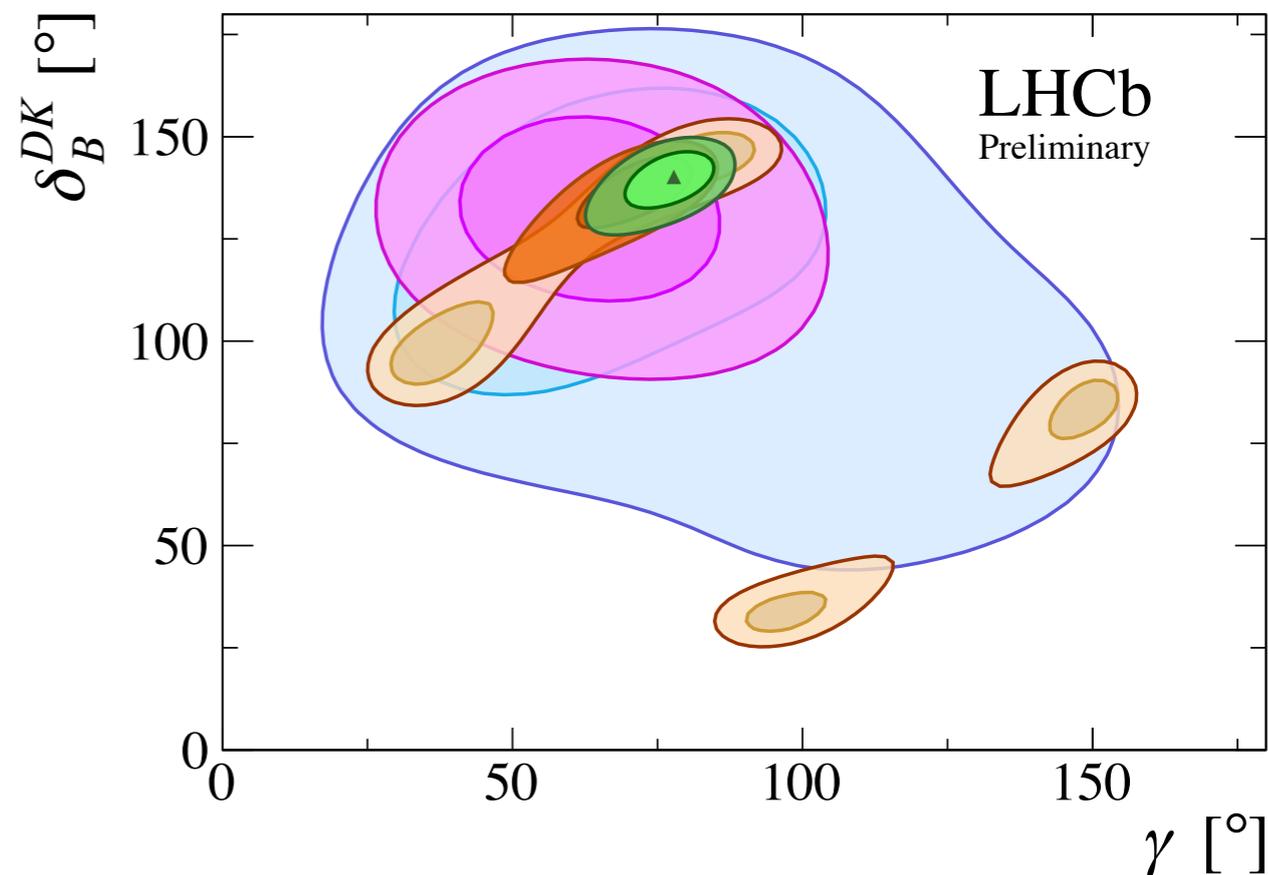
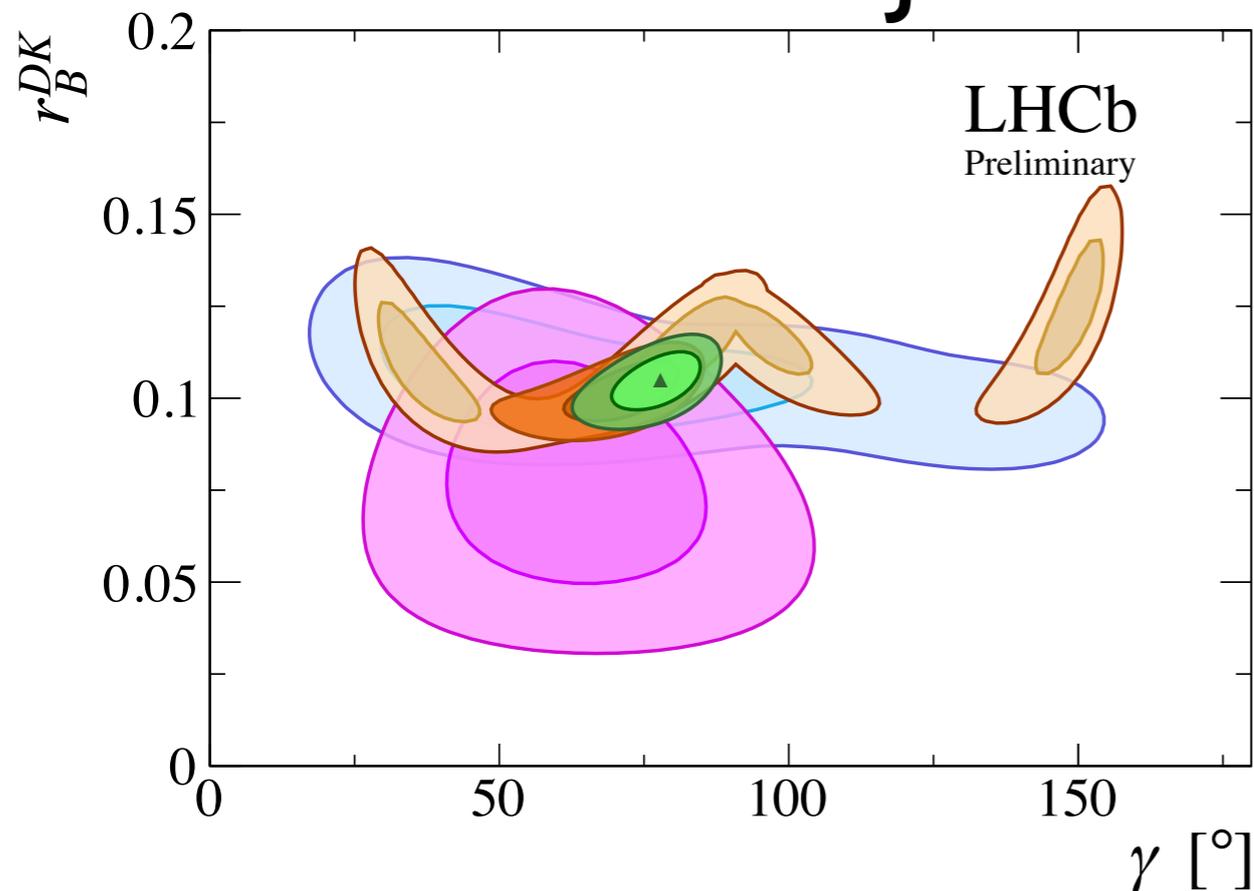


- | | | | |
|---|---|---|-----------------------|
|  | $B^+ \rightarrow DK^+, D \rightarrow h3\pi/hh' \pi^0$ |  | All B^+ modes |
|  | $B^+ \rightarrow DK^+, D \rightarrow K_S^0 hh$ |  | Full LHCb Combination |
|  | $B^+ \rightarrow DK^+, D \rightarrow KK/K\pi/\pi\pi$ | | |

NEW

LHCb γ combination

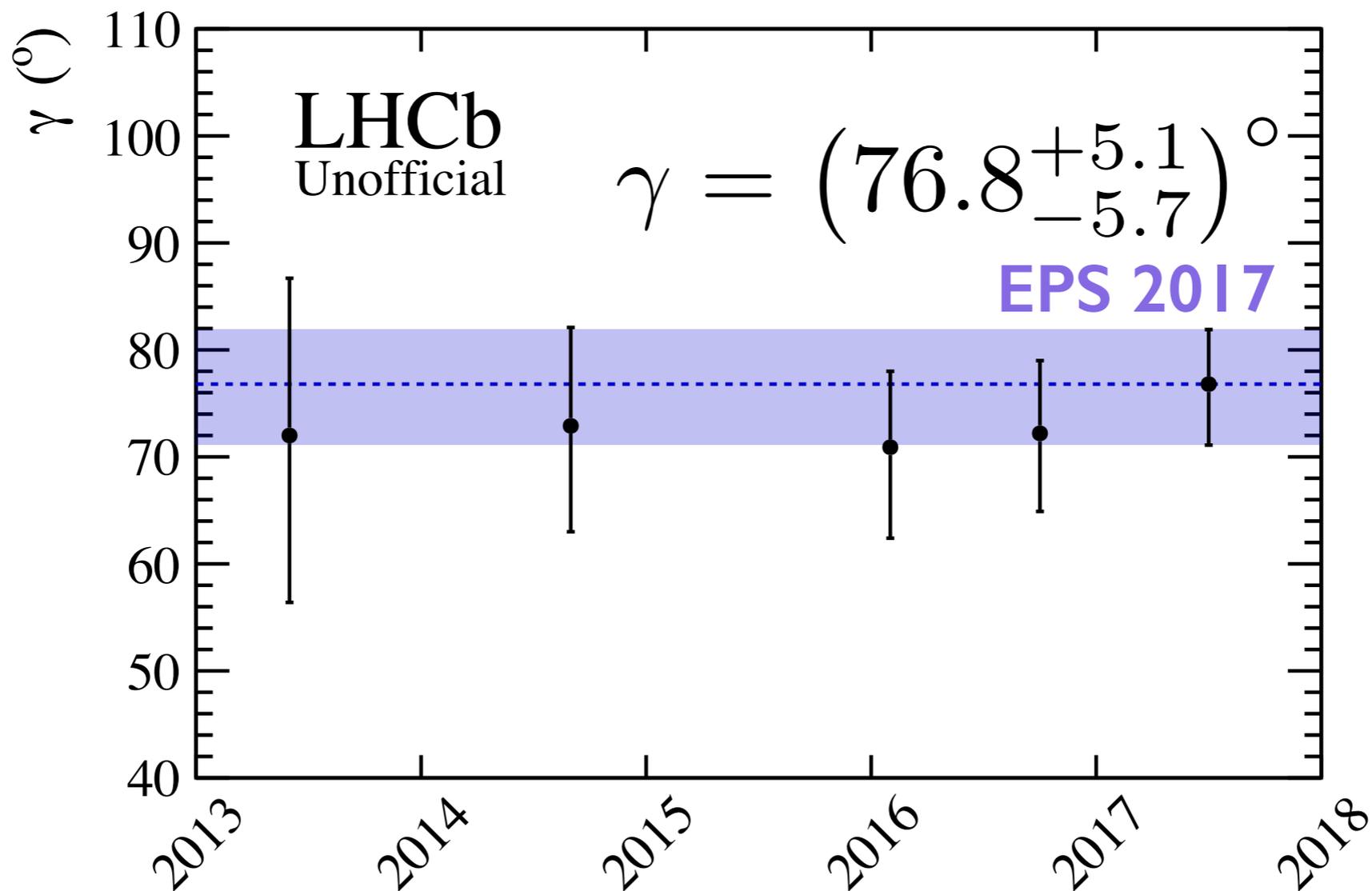
Jul 2017 CONF-2017-004



- | | | | |
|---|---|---|-----------------------|
|  | $B^+ \rightarrow DK^+, D \rightarrow h3\pi/hh' \pi^0$ |  | All B^+ modes |
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|  | $B^+ \rightarrow DK^+, D \rightarrow KK/K\pi/\pi\pi$ | | |

NEW

LHCb γ combination



Already a 30% improvement, with many more Run-II updates and channels expected soon.

Dominant contributor to new HFLAV average¹ $\gamma = (76.2^{+4.7}_{-5.0})^\circ$

[1] http://www.slac.stanford.edu/xorg/hflav/triangle/summer2017/index.shtml#gamma_comb

Conclusions

Tree-level b decays play a crucial role in testing CKM unitarity.

LHCb has a rapidly expanding program of studying semileptonic decays, making particular exploitation of b species that are only accessible at hadron colliders.

LHCb has competitive precision on $R(D^*)$ with first attempt using hadronic τ decays.

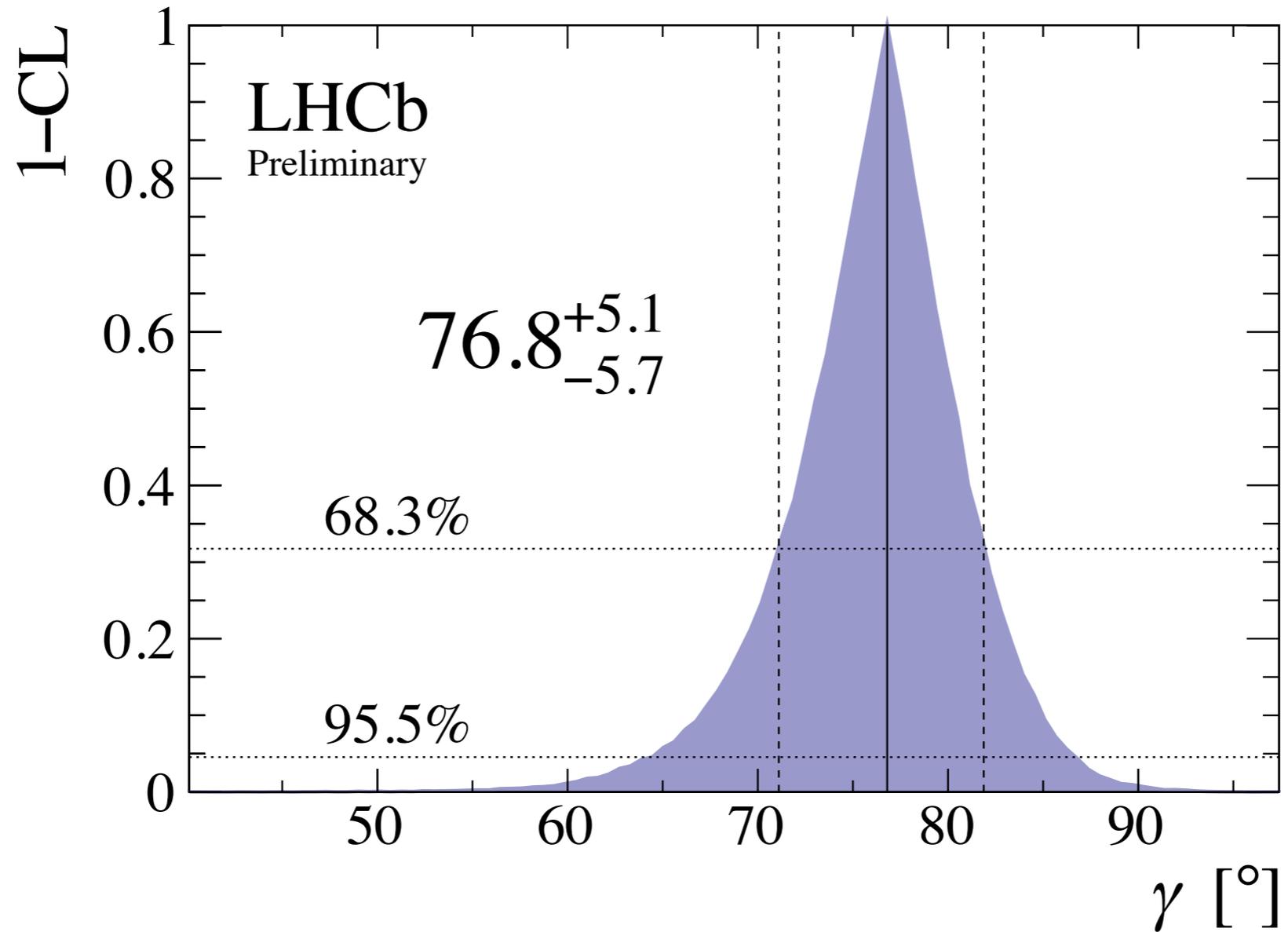
A new LHCb γ combination reaches $\sim 5^\circ$ precision.



Backup slides start here...

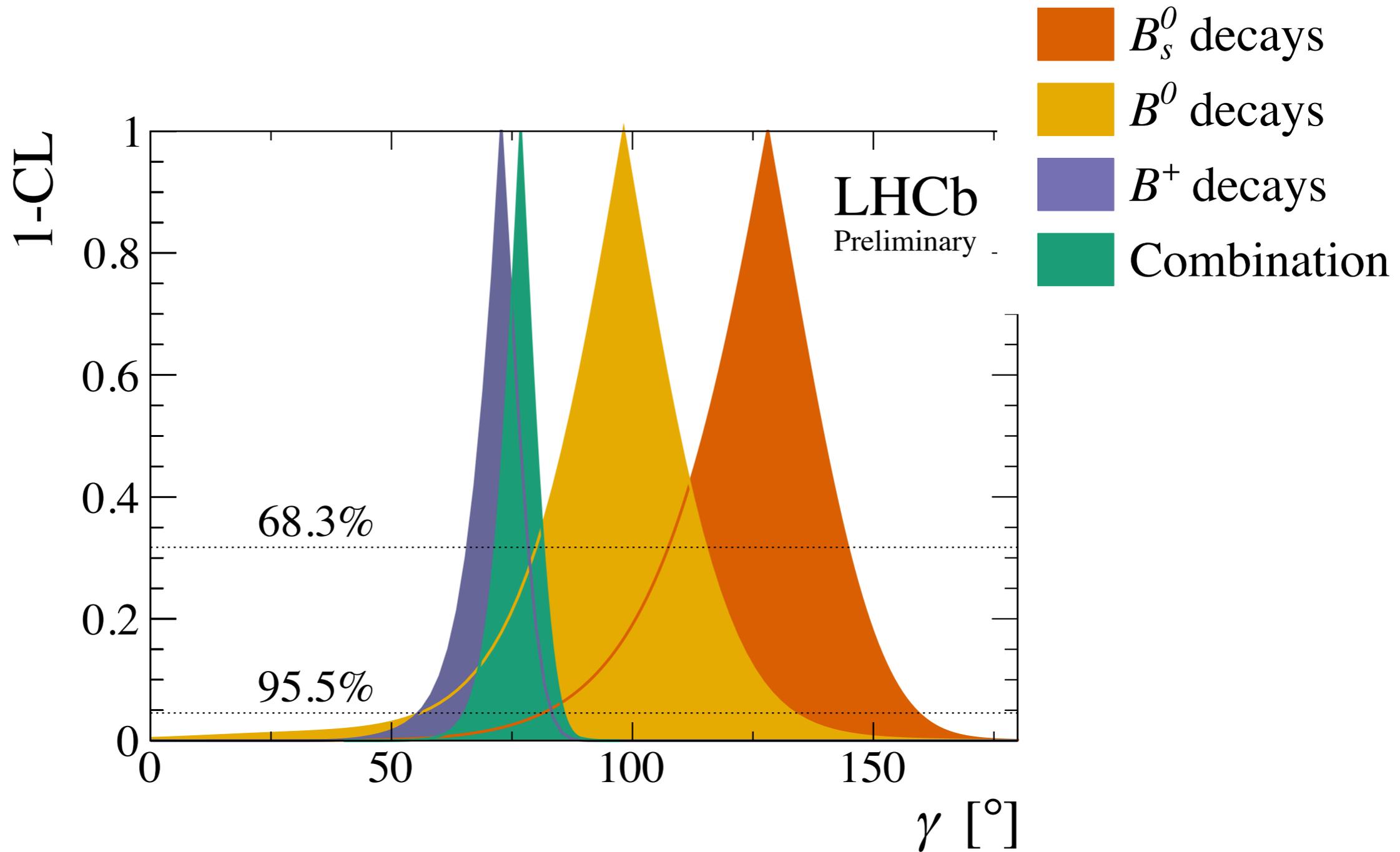
NEW

LHCb γ combination



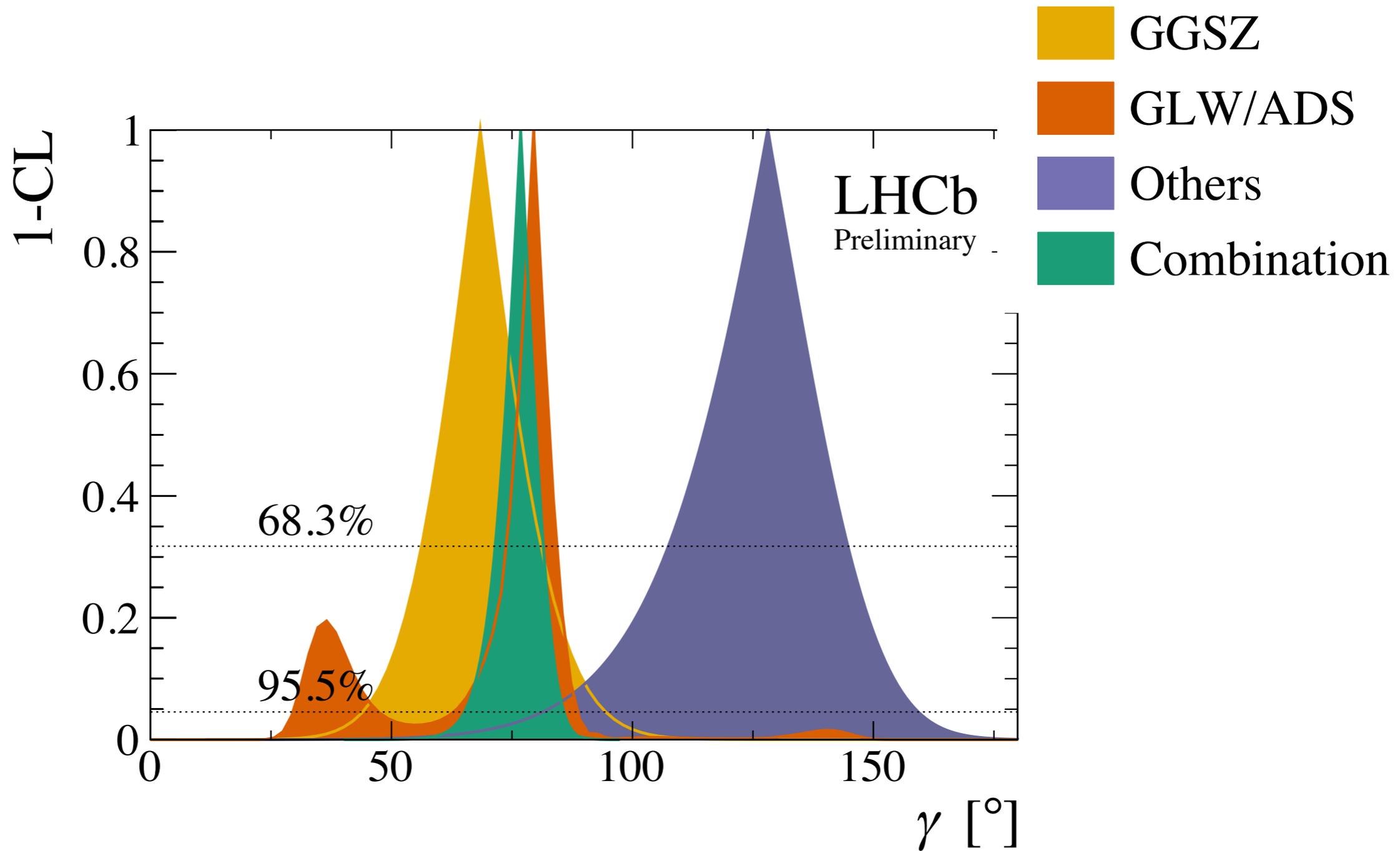


LHCb γ combination

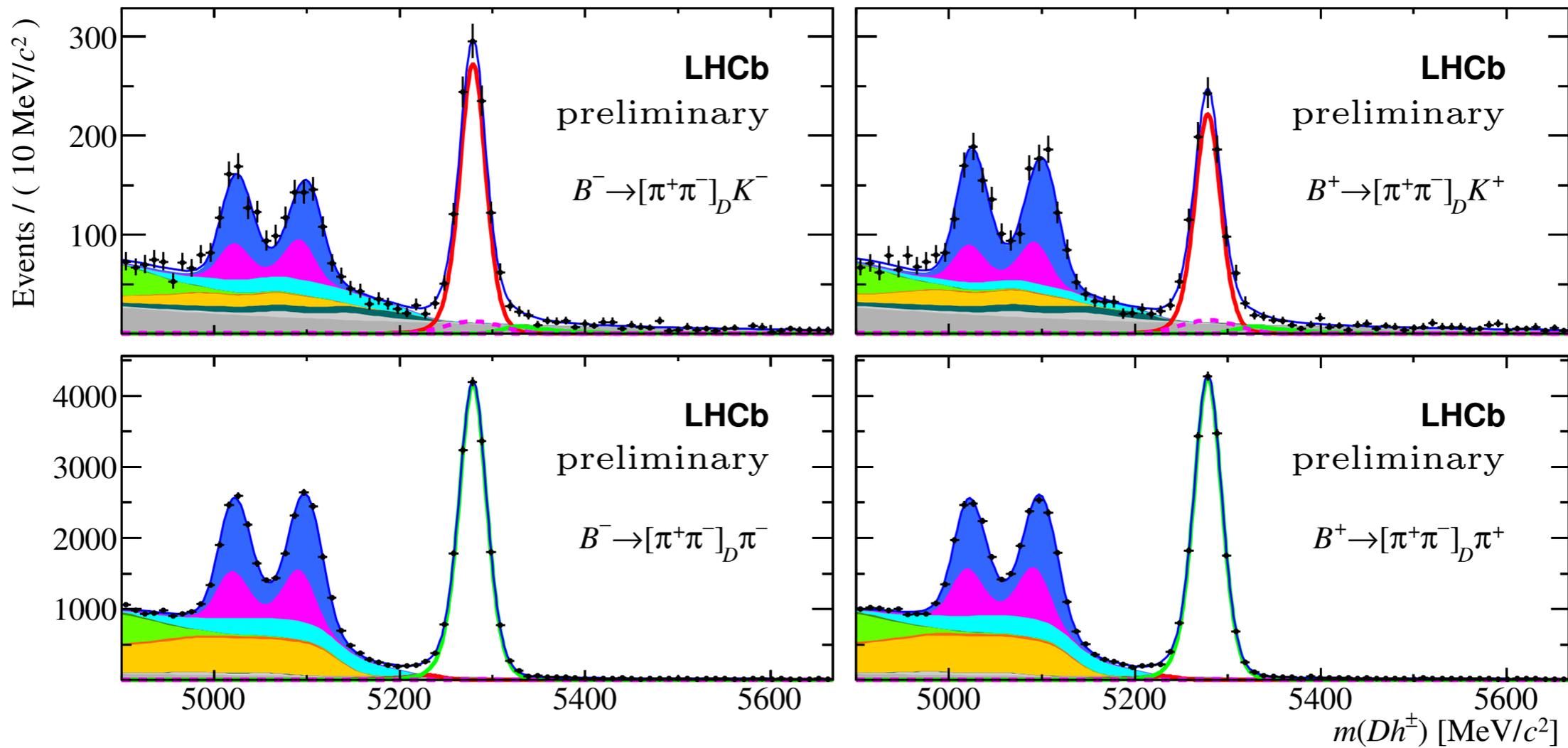
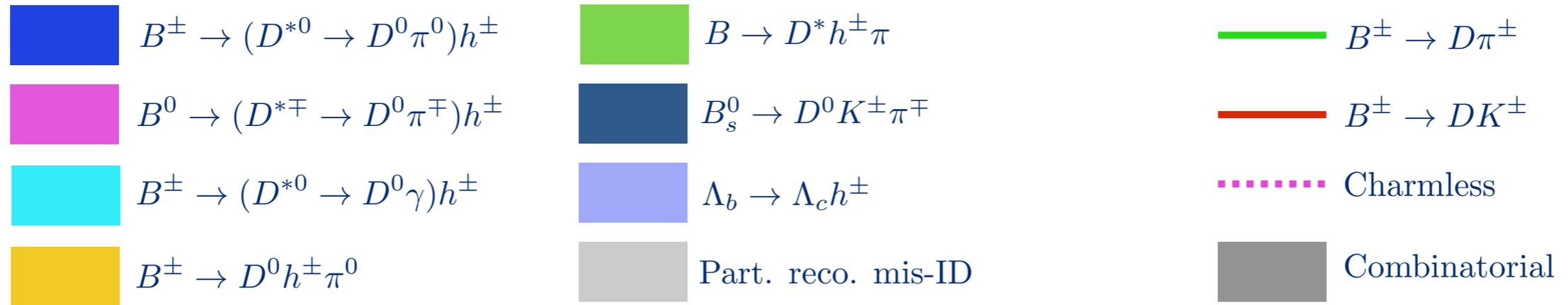




LHCb γ combination



GLW $\pi\pi$



New HFLAV γ average

