Experimental prospects for semileptonic decays

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Heavy Flavour 2016: Quo Vadis?

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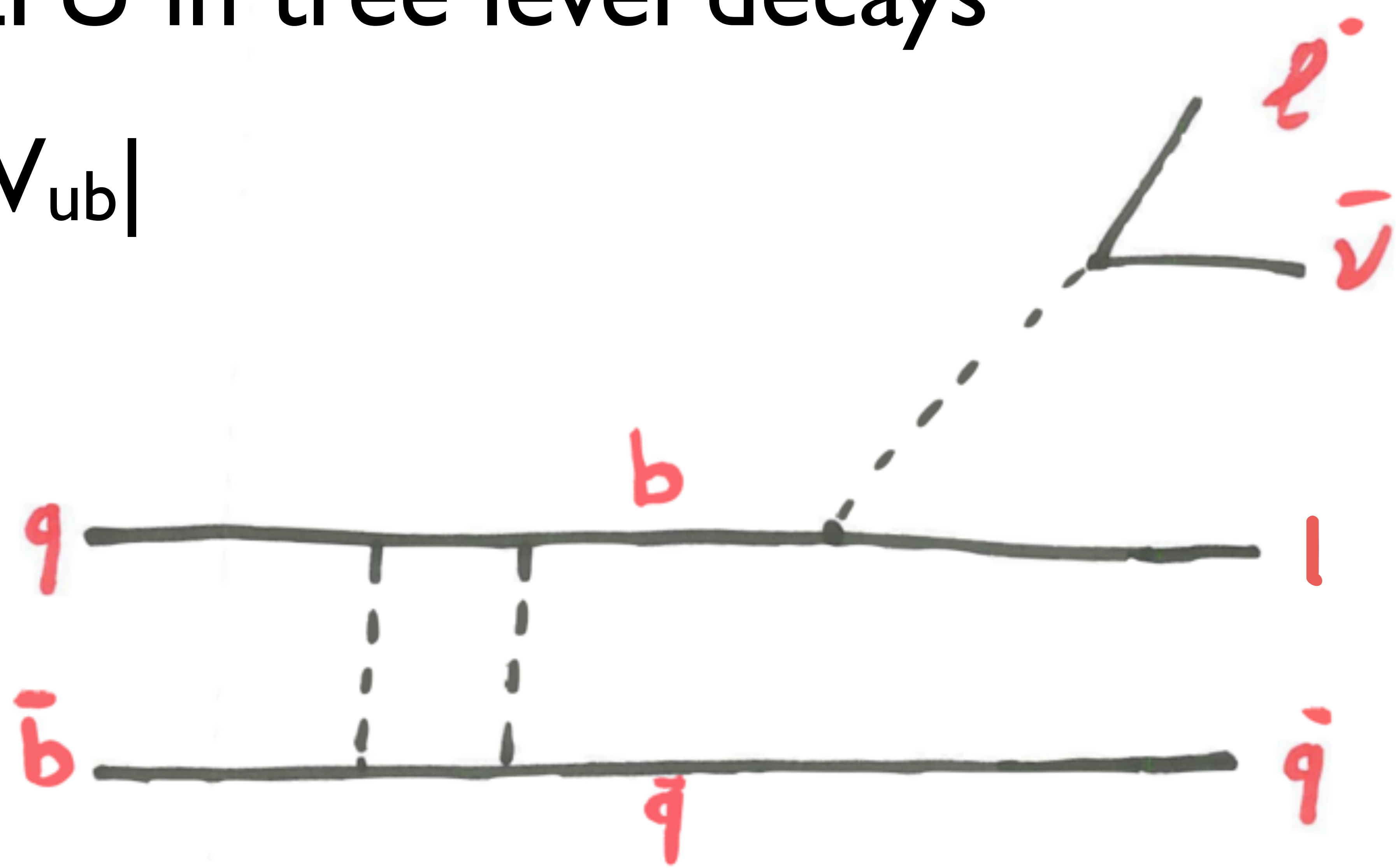
Outline

- The semileptonic asymmetries
- LFU in tree level decays
- $|V_{ub}|$



Semileptonic asymmetry

$$a_{\rm sl} \equiv \frac{\Gamma(\bar{B} \to f) - \Gamma(B \to \bar{f})}{\Gamma(\bar{B} \to f) + \Gamma(B \to \bar{f})} \approx \mathrm{Im}\left(\frac{\Gamma_{12}}{\mathrm{M}_{12}}\right)$$

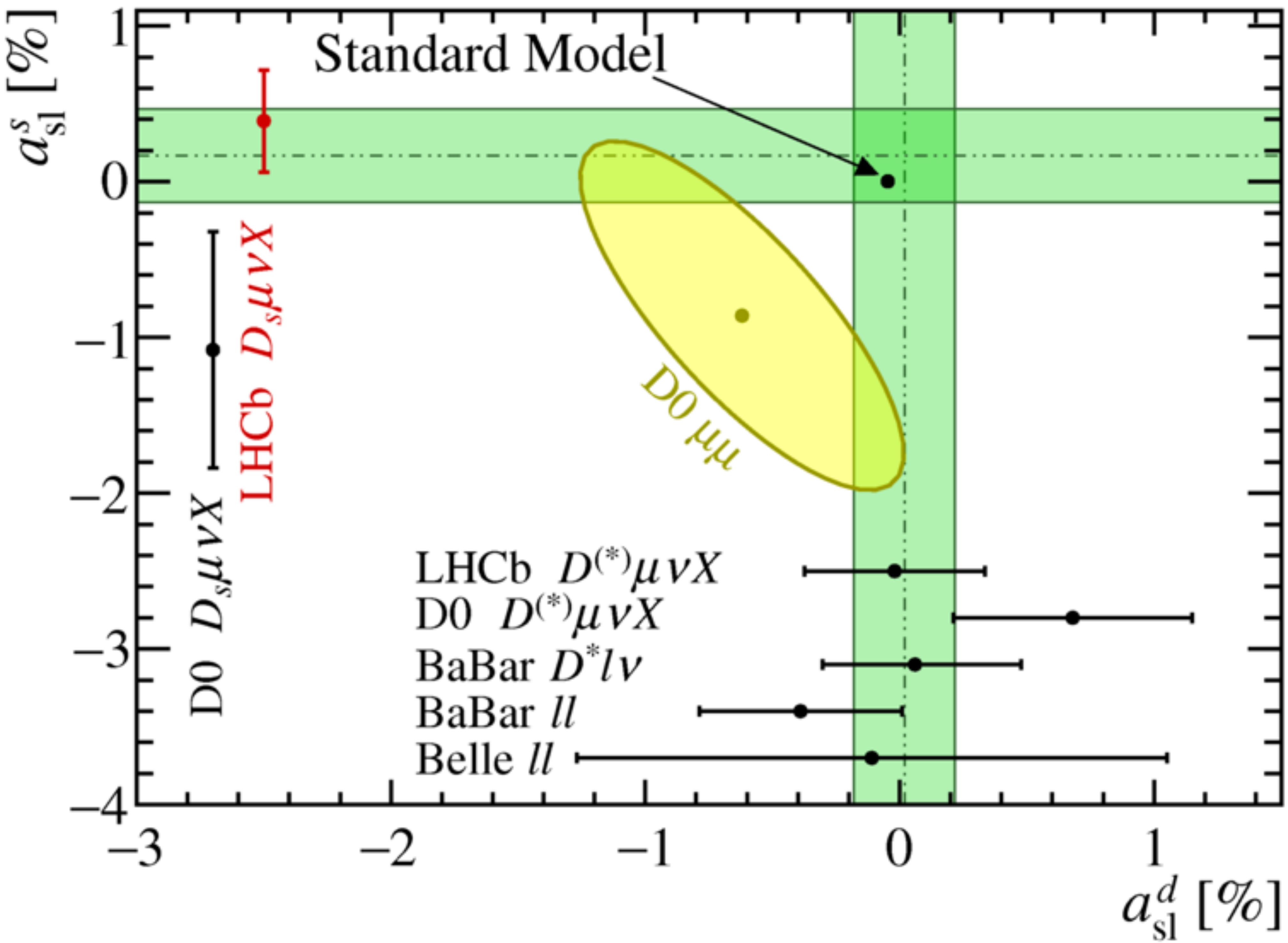
Standard Model predictions[1,2]

$$a_{\rm sl}^{d} = (-4.7 \pm 0.6) \times 10^{-4}$$

$$a_{\rm sl}^{s} = (2.22 \pm 0.27) \times 10^{-5}$$

[1] Lenz, Nierste, 0612167 (2007)
[2] Artuso, Borissov, Lenz, 1511.09466 (2016)

Experimental status



The dimuon asymmetry

- Measures[1]

$$A_{CP} = C_d a^d_{\rm sl} + C_s a^s_{\rm sl} + C_{\Delta\Gamma_d} \frac{\Delta\Gamma_d}{\Gamma_d}$$

- Final D0 statement[2]

$$a^d_{\rm sl} = (-0.62 \pm 0.43) \times 10^{-2},$$
$$a^s_{\rm sl} = (-0.82 \pm 0.99) \times 10^{-2},$$
$$\frac{\Delta\Gamma_d}{\Gamma_d} = (+0.50 \pm 1.38) \times 10^{-2}.$$

3.6σ from SM*

[1] 10.1103/PhysRevD.87.074020
[2] PRD 89, 012002 (2014)
*U. Nierste pointed out (CKM 2014) that the $\Delta\Gamma_d$ correction was overestimated

LHCb a^d_{sl}

PRL 114 041601 (2015)

Decay time dependent, untagged, asymmetry between B and Bbar:

$$\frac{\Gamma(D^-\mu^+\nu,t)-\Gamma(D^+\mu^-\nu,t)}{\Gamma(D^-\mu^+\nu,t)+\Gamma(D^+\mu^-\nu,t)}$$

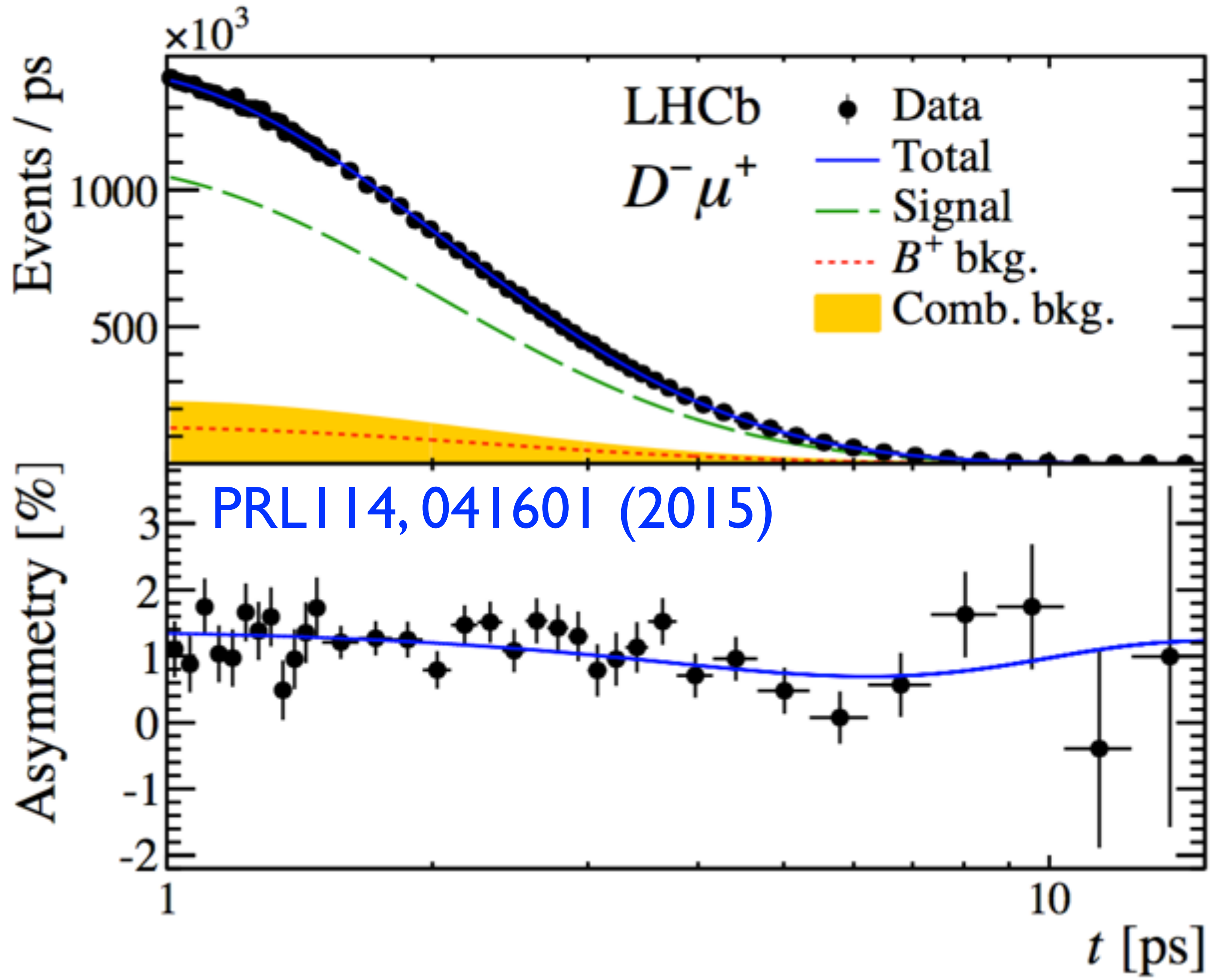
$$=\frac{a_{\rm sl}}{2}-\left[A_P+\frac{a_{\rm sl}}{2}\right]\frac{e^{-\Gamma t}\cos(\Delta m\, t)\epsilon(t)}{e^{-\Gamma t}\cosh\frac{\Delta\Gamma\, t}{2}\epsilon(t)}$$

Time dependent study needed to disentangle A_P and a_{sl}.

A_P is the asymmetry between the production rates of B and Bbar.

PRL 114 041601 (2015)

LHCb a^d_{sl}



$$a^d_{sl} = (-0.02 \pm 0.19 \pm 0.30)\%$$

Also measure the B^0 production asymmetries at 7 and 8 TeV

[PRL 114, 041601 (2016)]

LHCb a^s_{sl}

- Effect of production asymmetry washed out by fast oscillations.

- Simply measure:

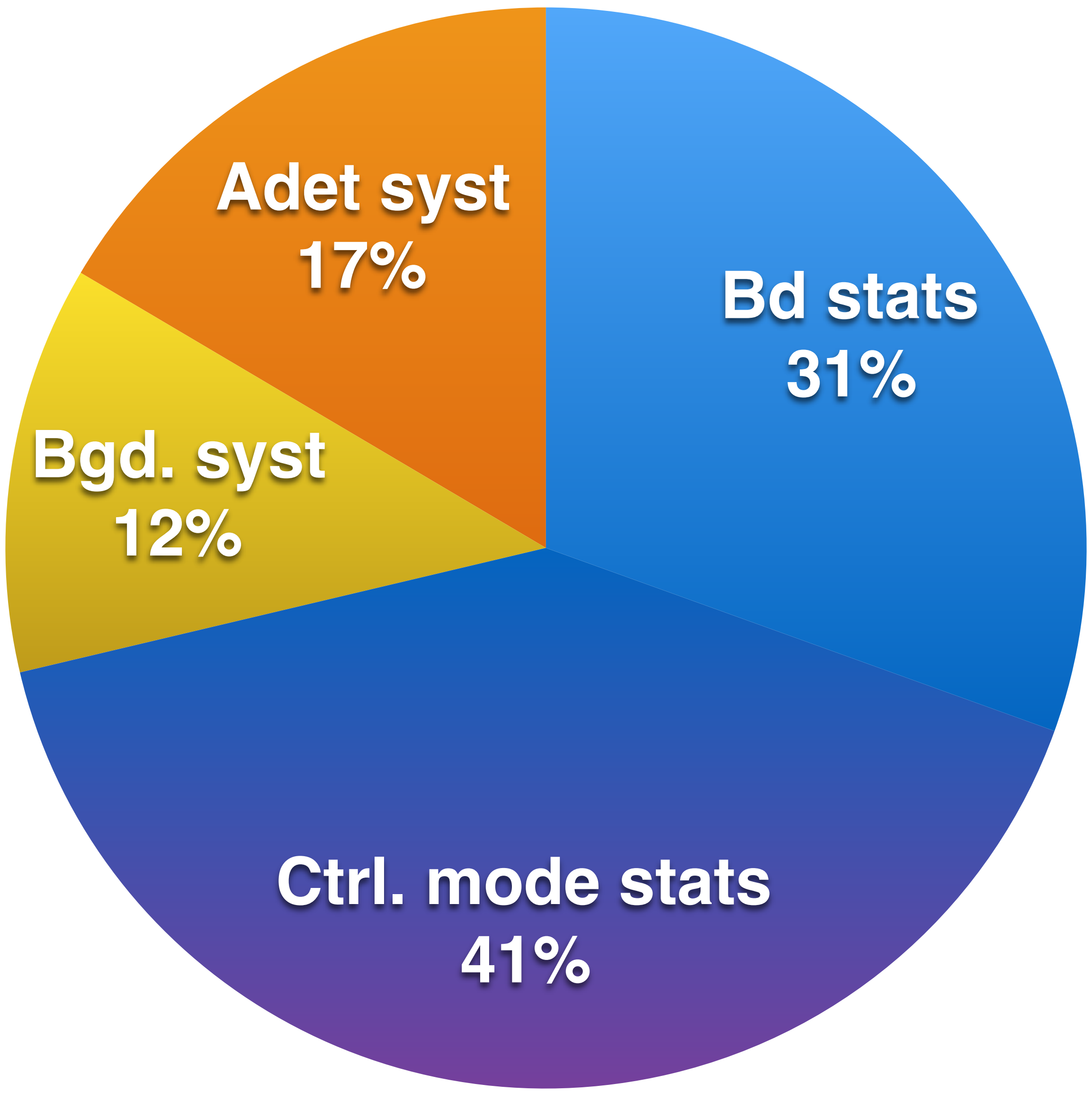
$$\frac{\Gamma[D_s^-\mu^+] - \Gamma[D_s^+\mu^-]}{\Gamma[D_s^-\mu^+] + \Gamma[D_s^+\mu^-]} \approx \frac{a_{sl}}{2}$$

With ≈1.5 million $B_s \rightarrow D_s \mu \nu$ candidates in Run-1 dataset[1]

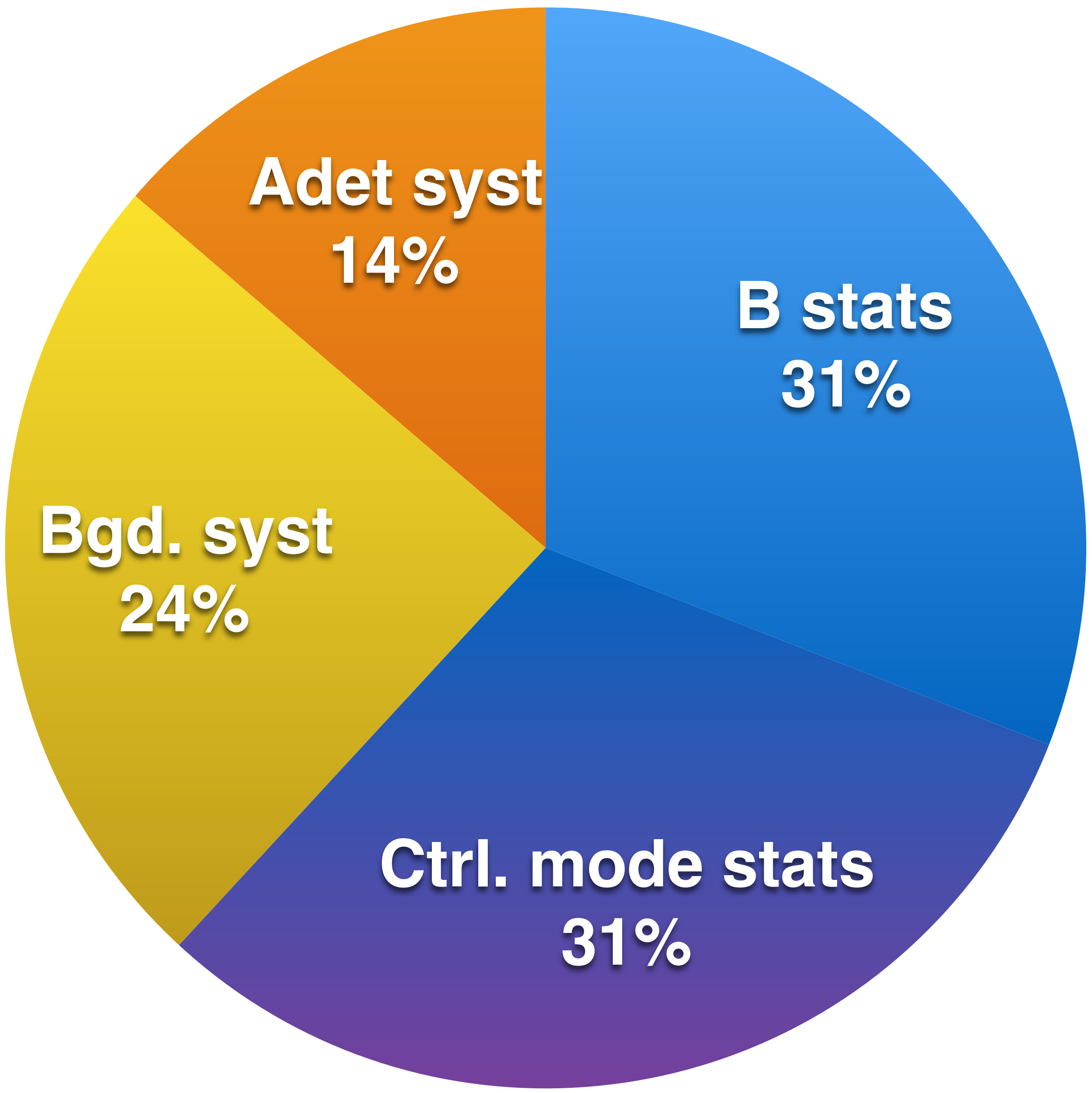
$$a^s_{sl} = (0.39 \pm 0.26 \pm 0.20)\%$$

LHCb error budgets

$\delta a^{d}_{sl} = \pm 35\times 10^{-4}$



$\delta a^{s}_{sl} = \pm 33\times 10^{-4}$



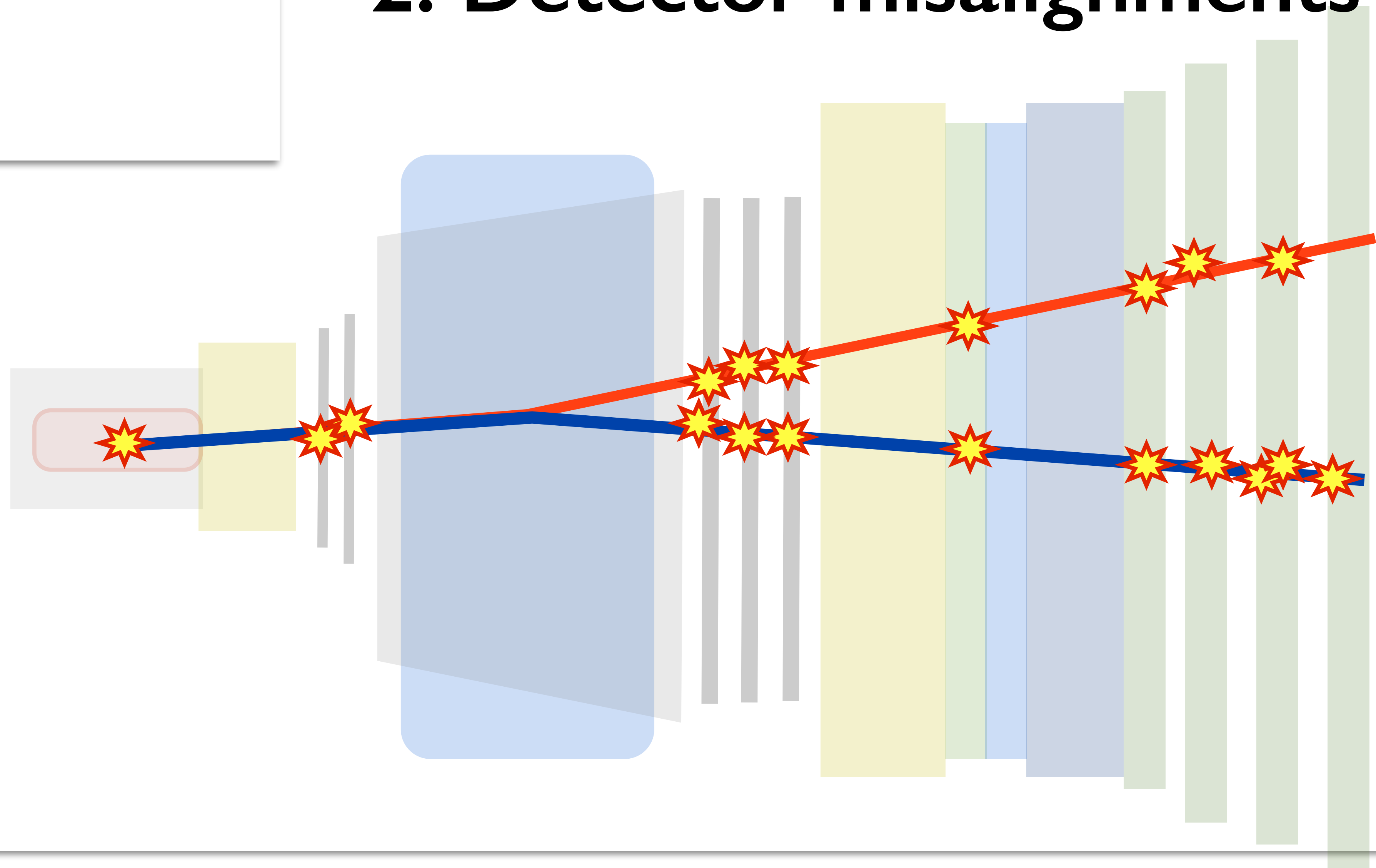
1. PRL 114 041601 (2015)
2. LHCb, 1605.09768 (2016)

Detection asymmetries

1: Nuclear interactions

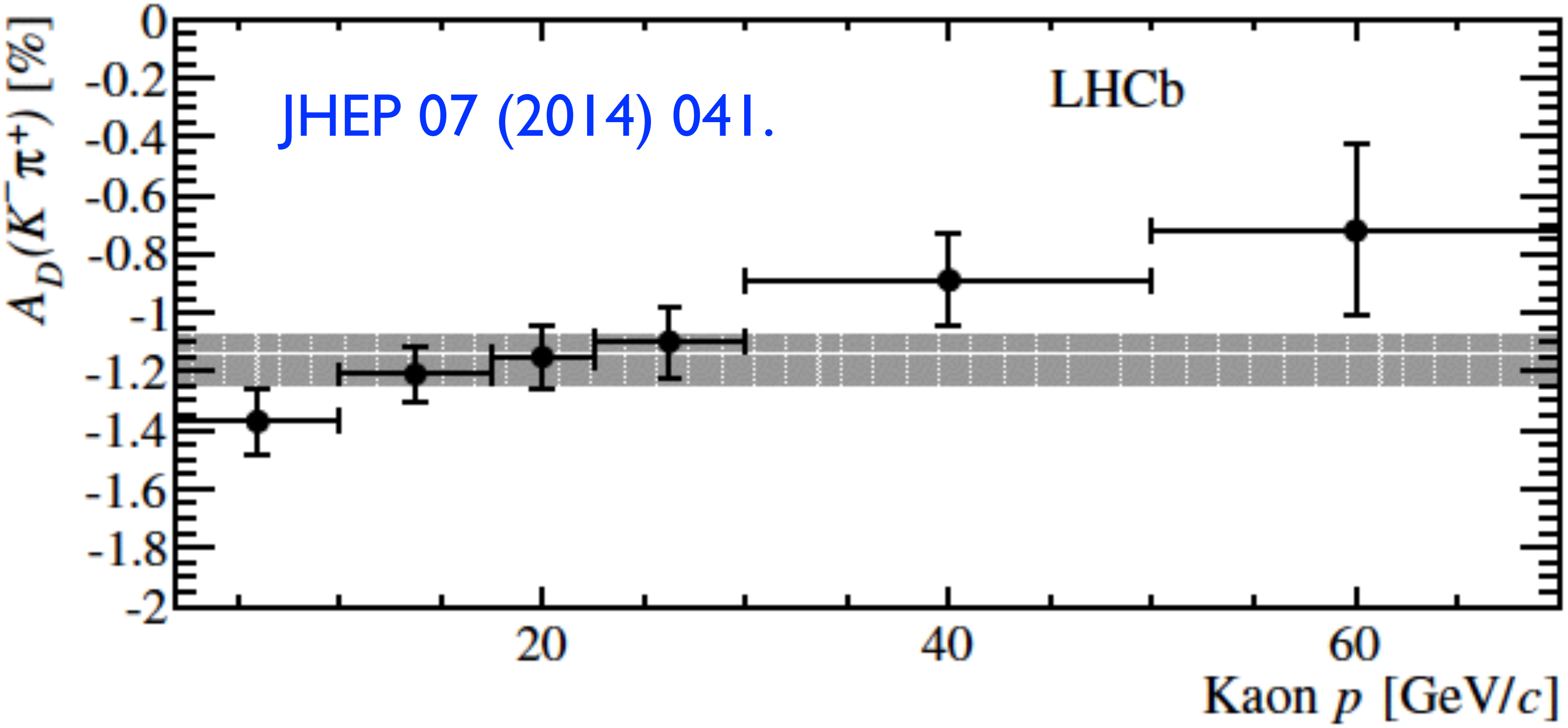
$$\frac{\sigma(K^-N)}{\sigma(K^+N)} \sim 1.3$$

2: Detector misalignments



Kaon asymmetry

Method using combination of CF charm decays:

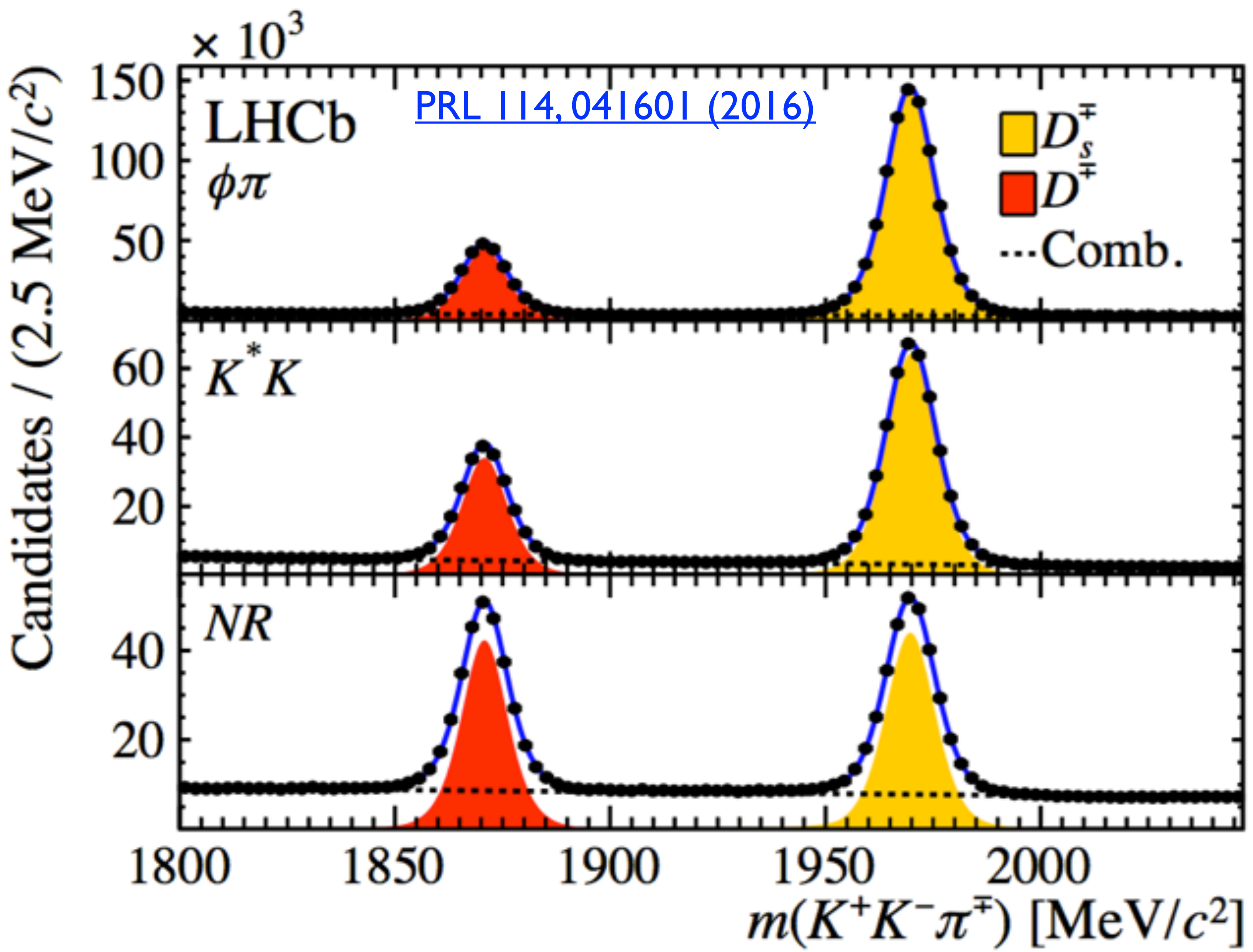


Limited by yields of $D^+ \to K_s\pi^+$ decays (~10^6 in Run-I)

Completely new method in the pipeline for Run-II

Backgrounds

Little problem to count $D_s \to KK\pi$ decays:



PRL 114, 041601 (2016)

Backgrounds

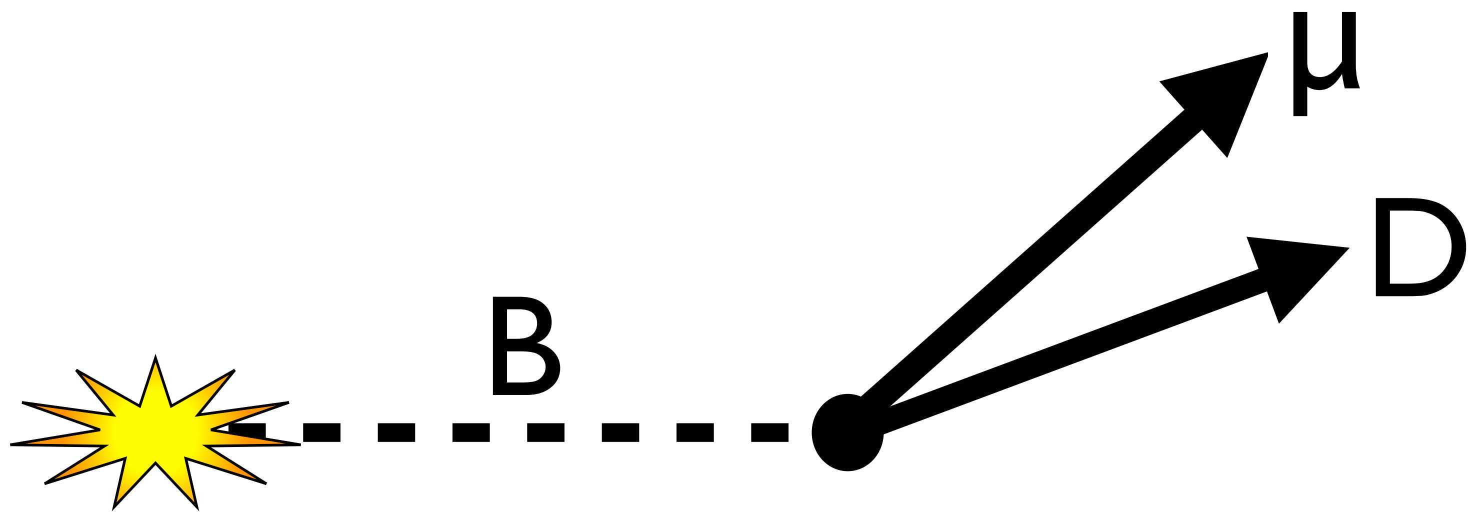
However, many sources of $D_s \mu X$, e.g:

Source	Fraction
$B \to DDX$	13%
$\Lambda \to \Lambda_c D_s X$	3%
$B \to D_s K \mu \nu X$	2%

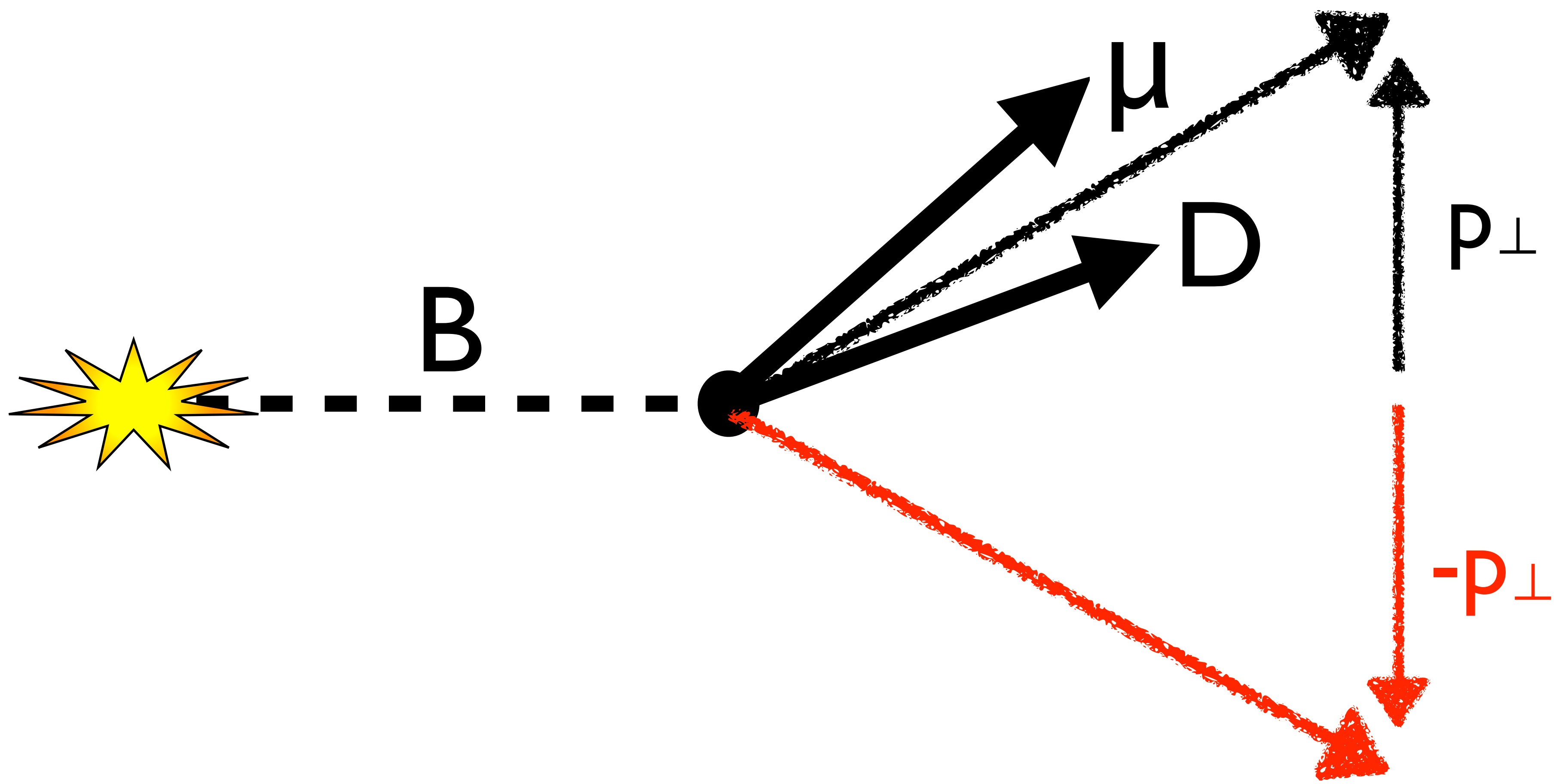
Background fraction	(18 ± 6)%
Correction to a^s_{sl}	$(-0.04 \pm 0.06) \times 10^{-2}$

PRL 114, 041601 (2016)

Corrected mass



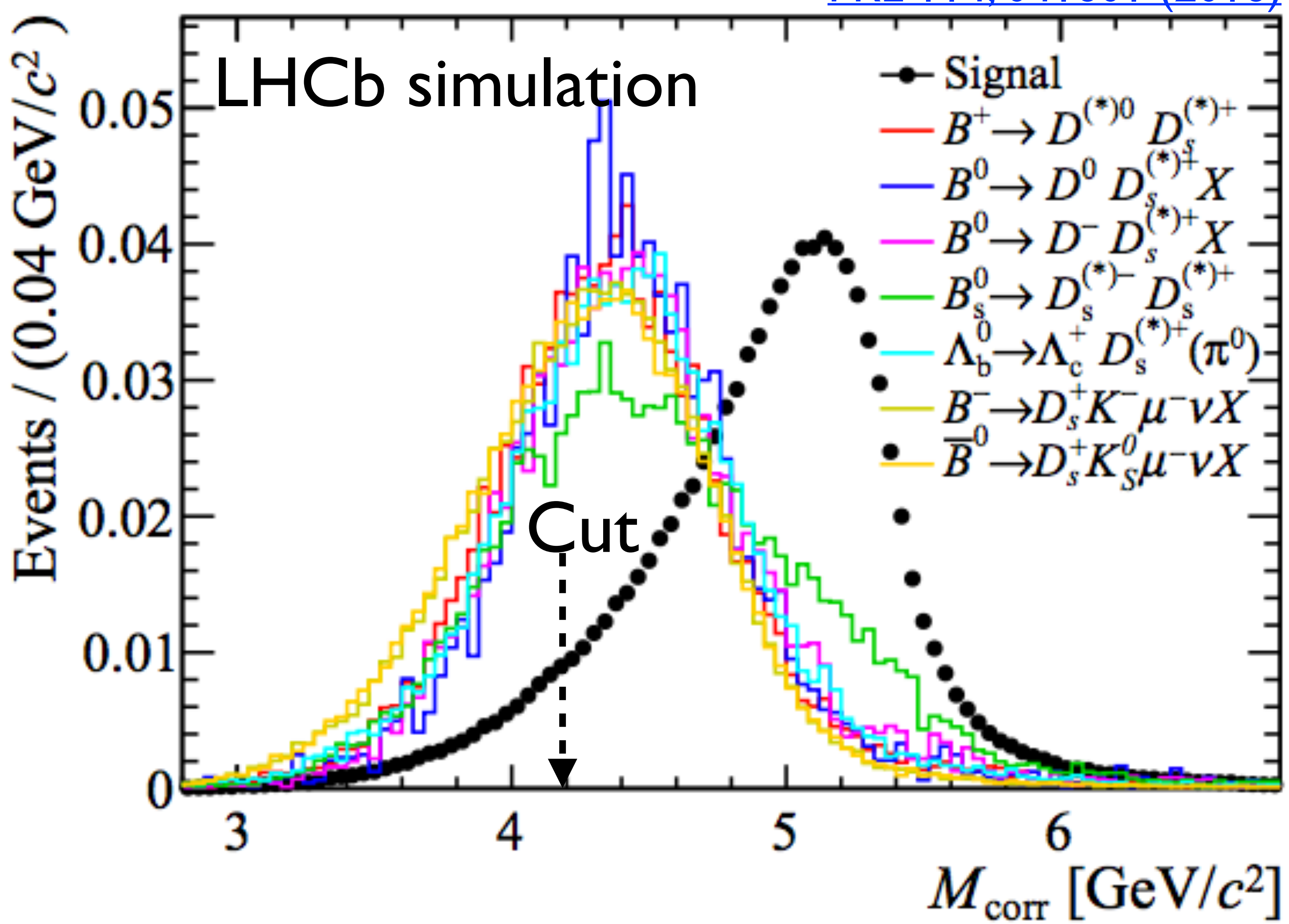
Corrected mass



$$M_{\mathrm{corr}} = \sqrt{m_{\mathrm{vis}}^2 + p_{\perp}^2} + p_{\perp}$$

$B_s \to D_s \mu \nu$ corrected mass

PRL 114, 041601 (2016)



Future analyses to fit this distribution and subtract all non B_s backgrounds

Alternative view of a^s_{sl}

- Fleischer, Vos, 2016 [1606.06042]
- Combination of ΔM_s, $\Delta\Gamma_s$ and ϕ_s, allowing for NP:

  $a^s_{sl} = (0.014 \pm 0.018)\%$

- Suggested to use $B_s \to D_s \mu X$ decays to measure $A_P(B_s)$ and $A_{CP}(D_s \to KK\pi)$

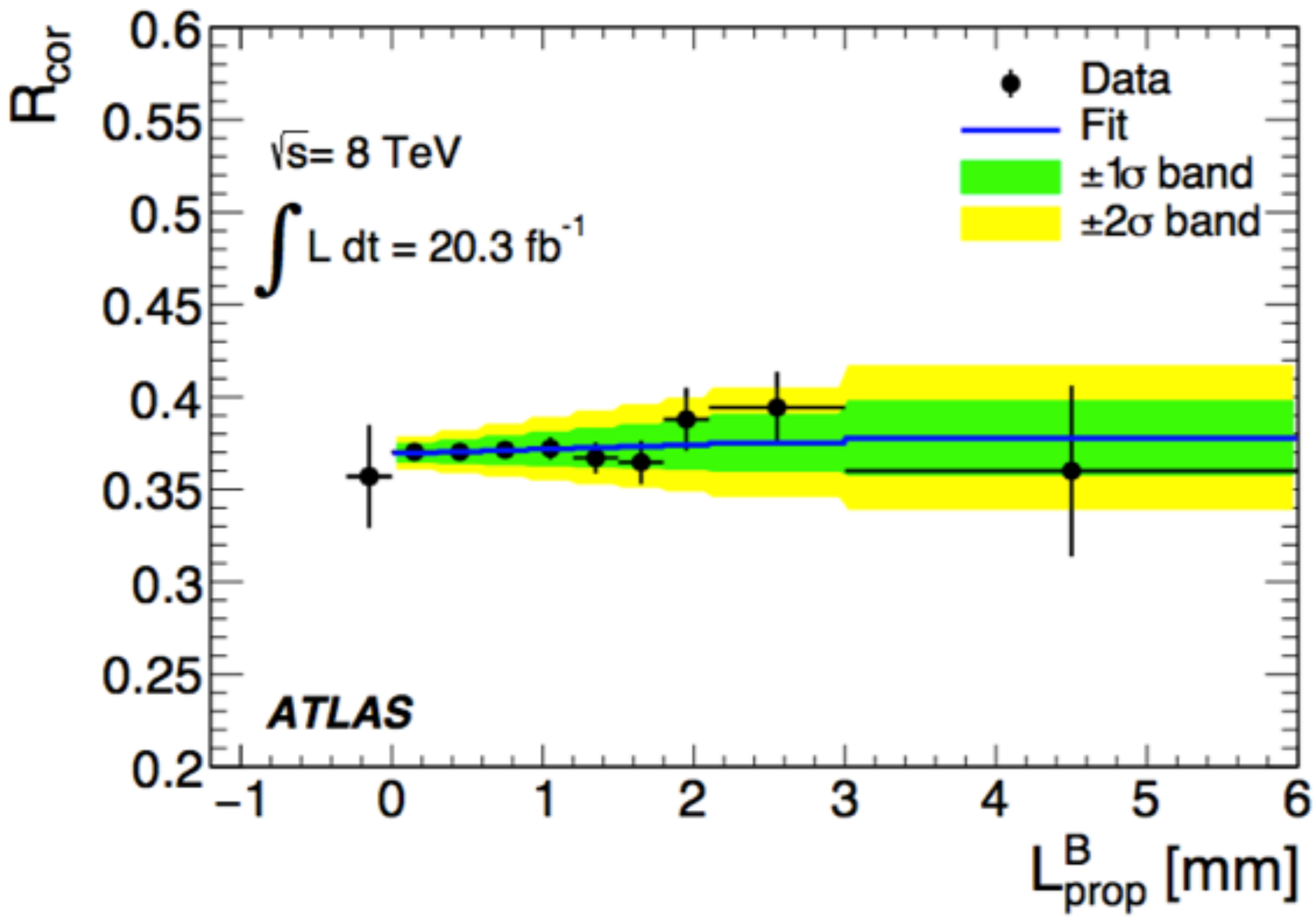
$$a_{\rm CP}^{(D_s)}|_{K^+K^-\pi^\mp} = (0.20 \pm 0.16) \times 10^{-2}$$

Requires time dependent analysis of semileptonic B_s decays. Not easy, but one existing measurement (see this slide)

JHEP06 (2016) 081

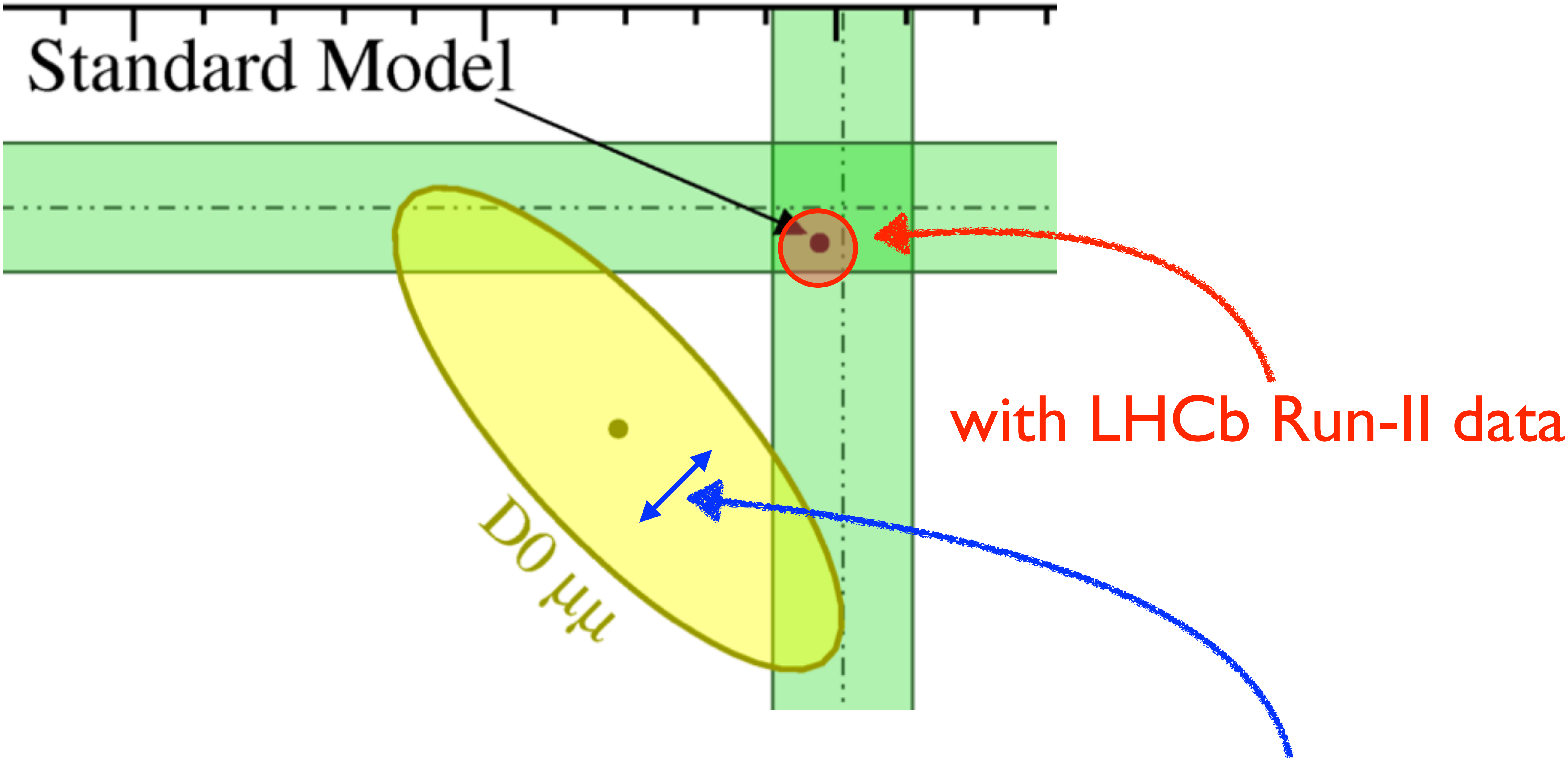
ATLAS $\Delta\Gamma_d$

Single most precise measurement using time dependent study of B_d decays into $J/\psi K^*$ and $J/\psi K_s$.



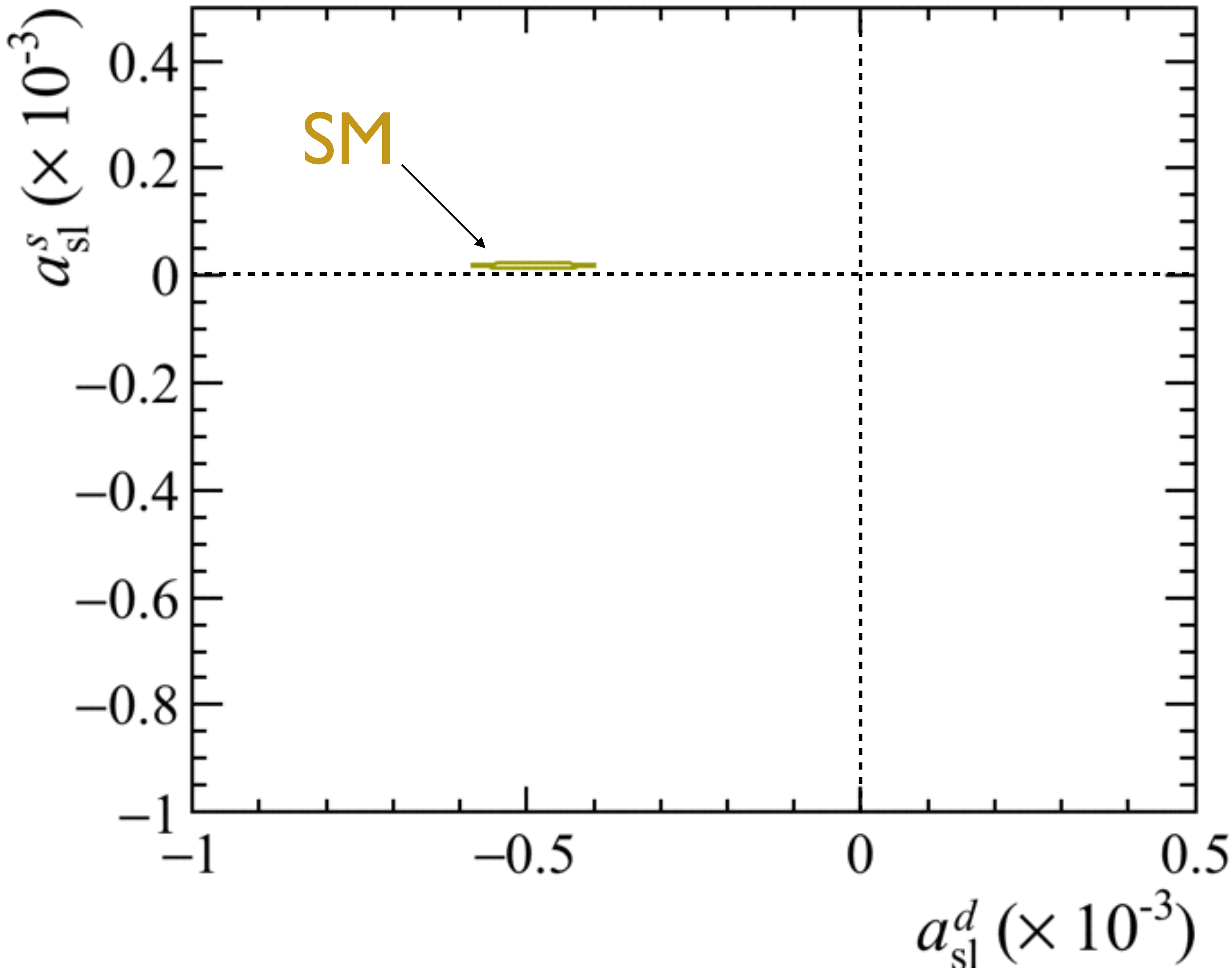
$$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1\,(\text{stat.}) \pm 0.9\,(\text{syst.})) \times 10^{-2}.$$

Outlook

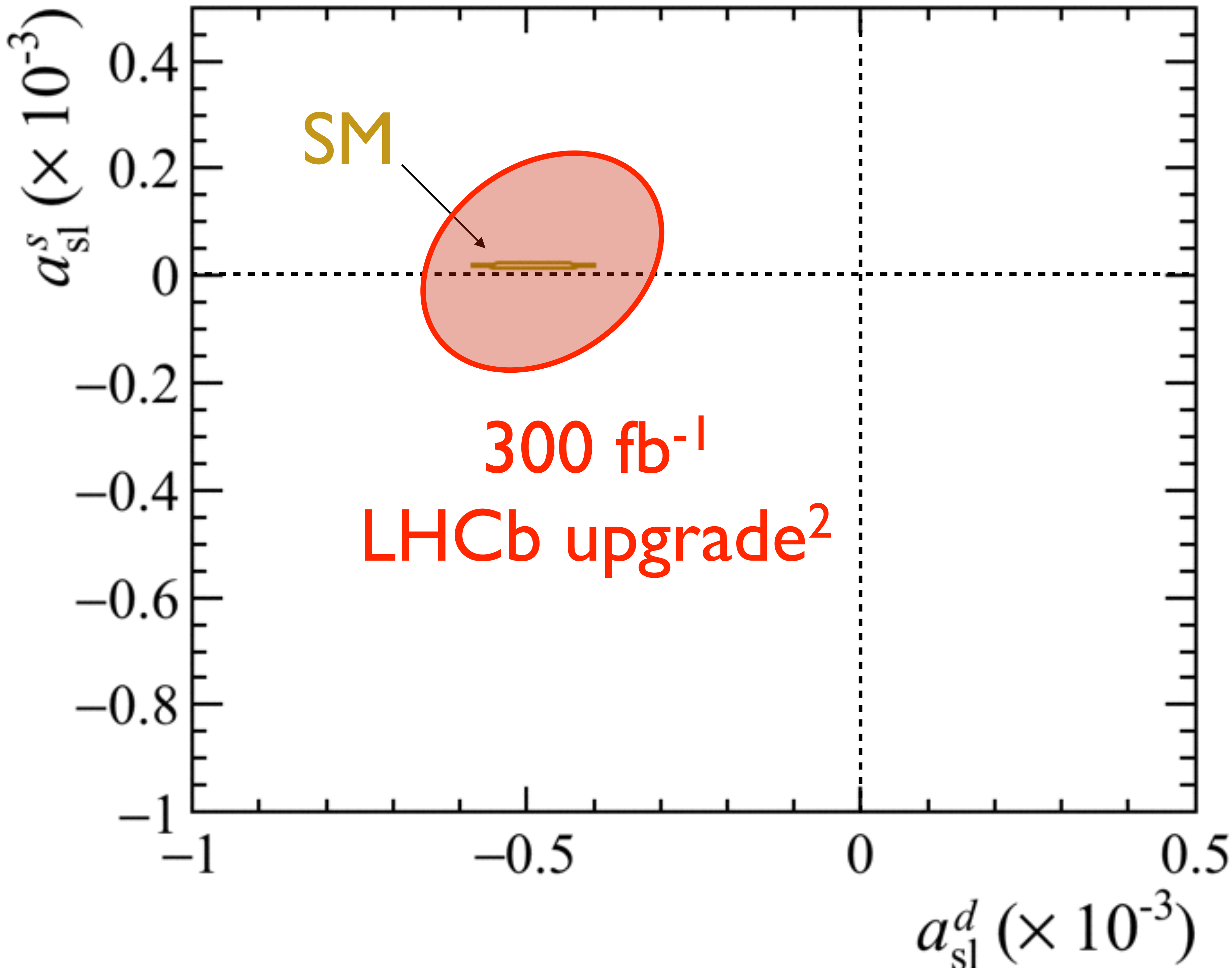


On the same timescale $\Delta\Gamma_d/\Gamma_d$ uncertainty at few x 10^{-3}

Outlook

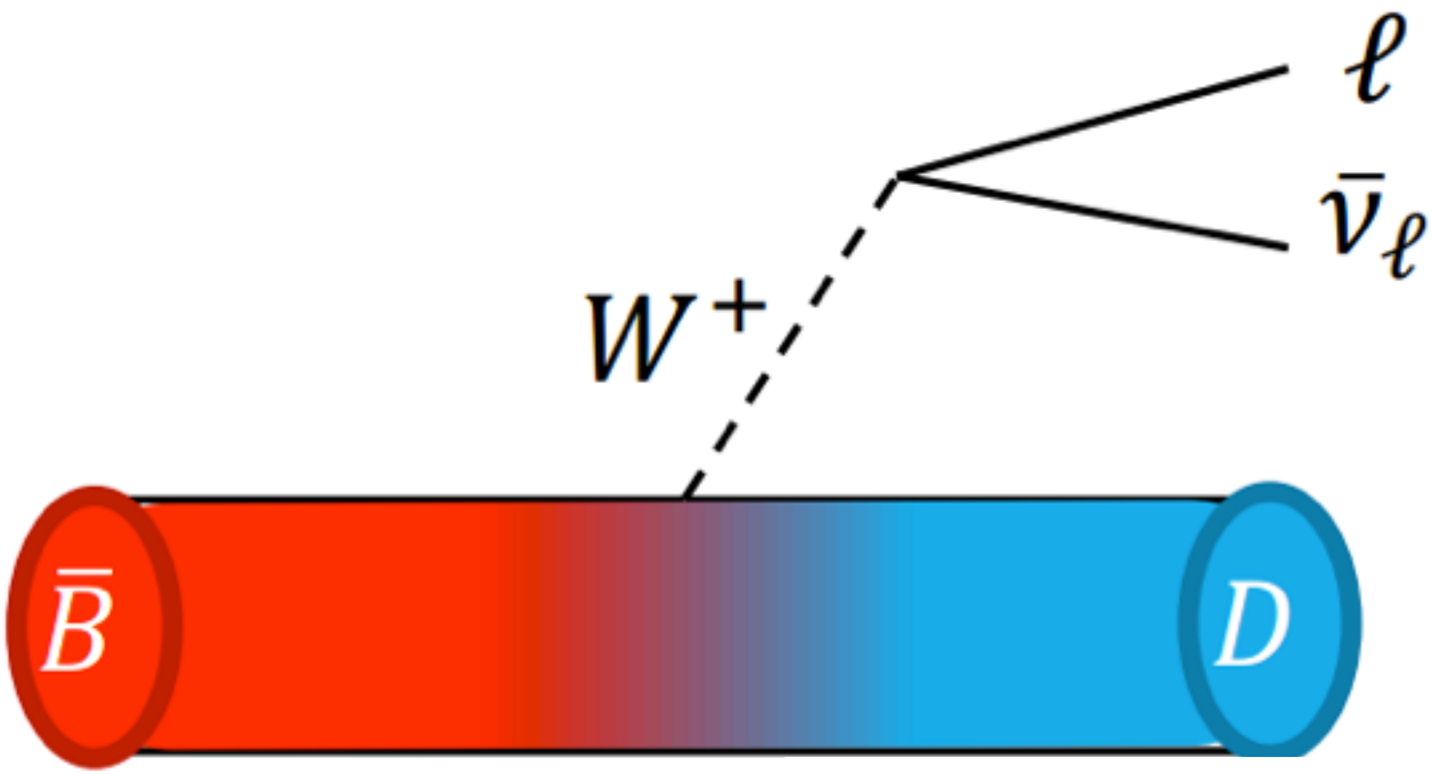


Outlook



Is this of theoretical interest though?

Tree level LFU

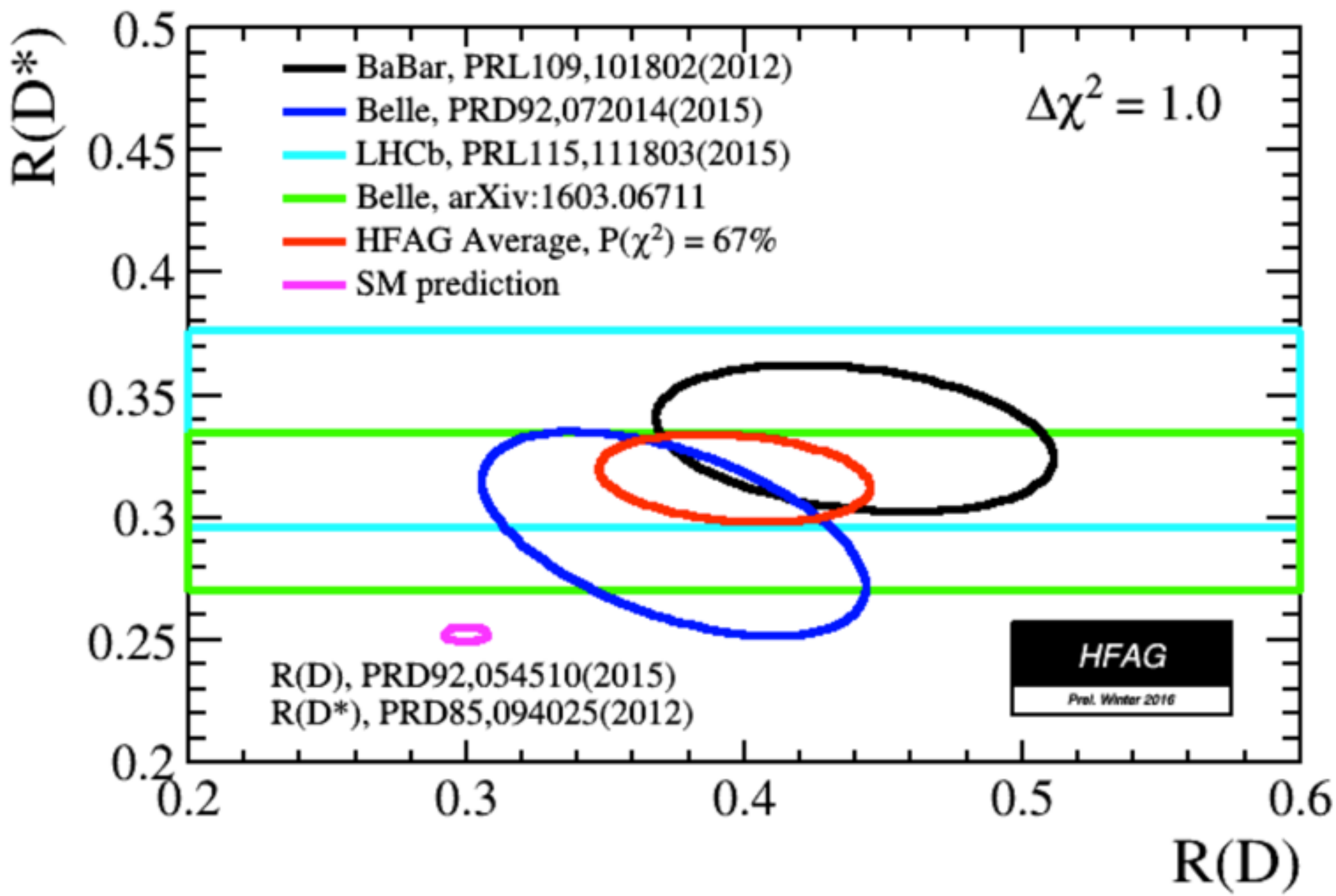


$$R(D^{*+}) \equiv \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\ell)}$$

Fajfer et al., 2012 PRD 85 094025

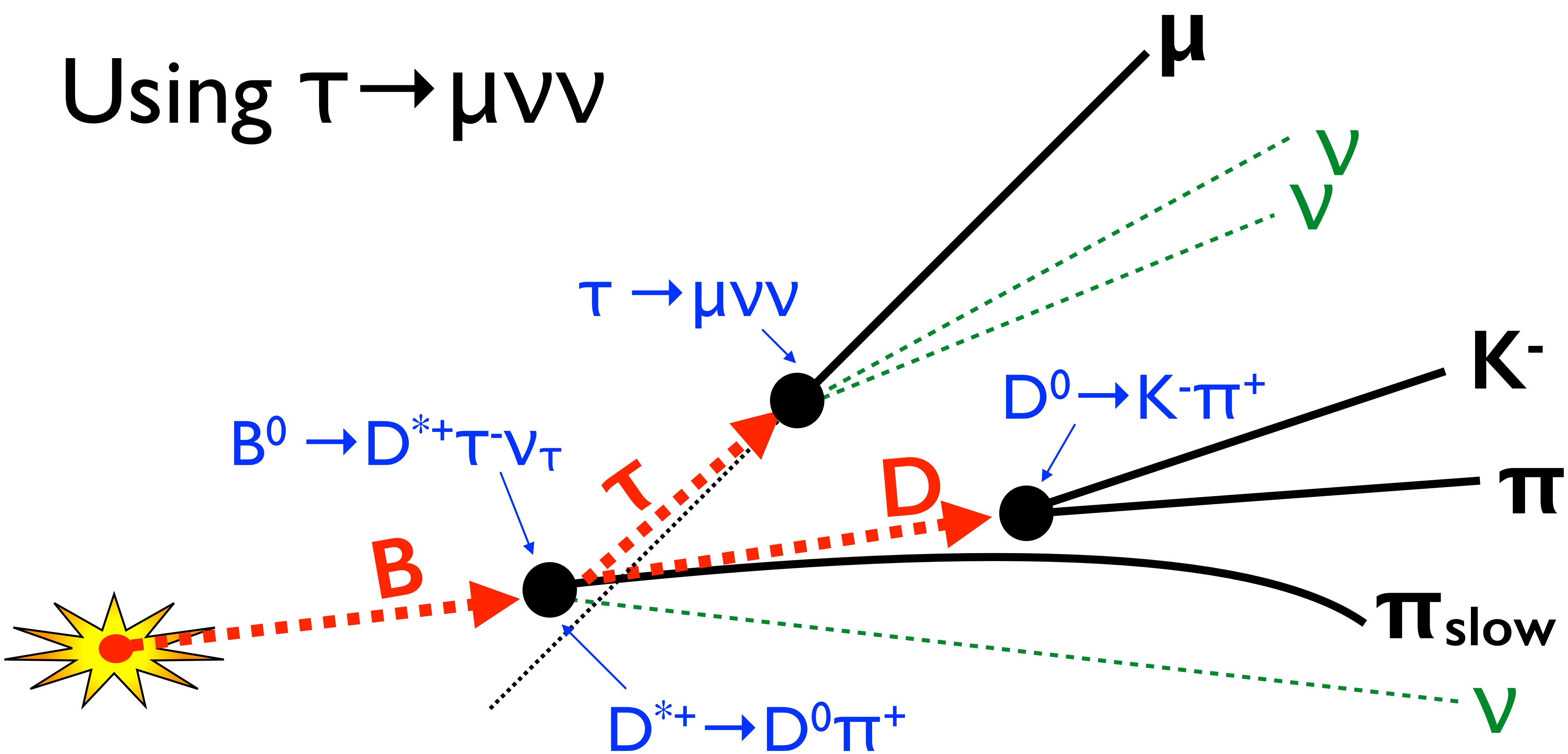
$R(D^*)_{\mathrm{HQET}} = 0.252(3)$

$R(D^{(*)})$ experimental status



LHCb $R(D^*)$

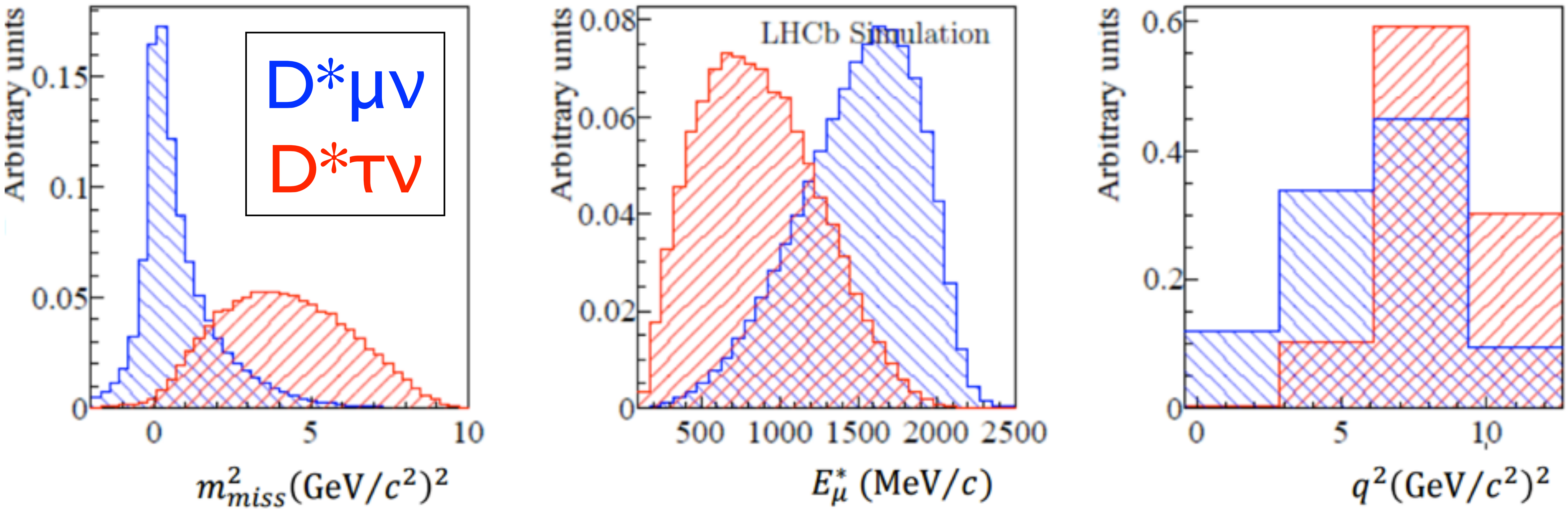
Using $\tau \to \mu\nu\nu$



The signal isn't rare: ≈10^{-4} after selections

Hard to isolate though: signal/normalisation ~ 4%

Kinematics

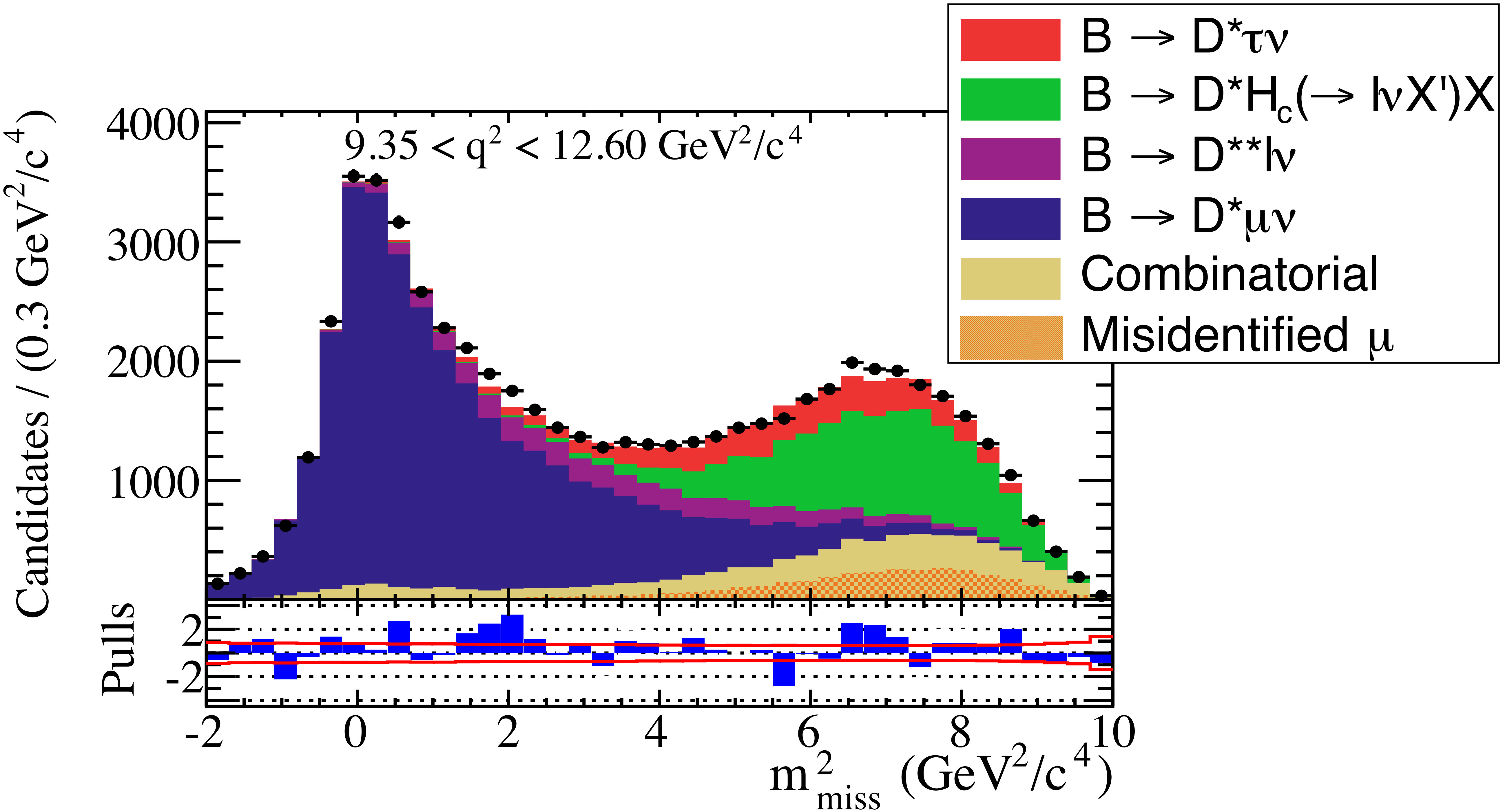


Actually one of the easier backgrounds though....

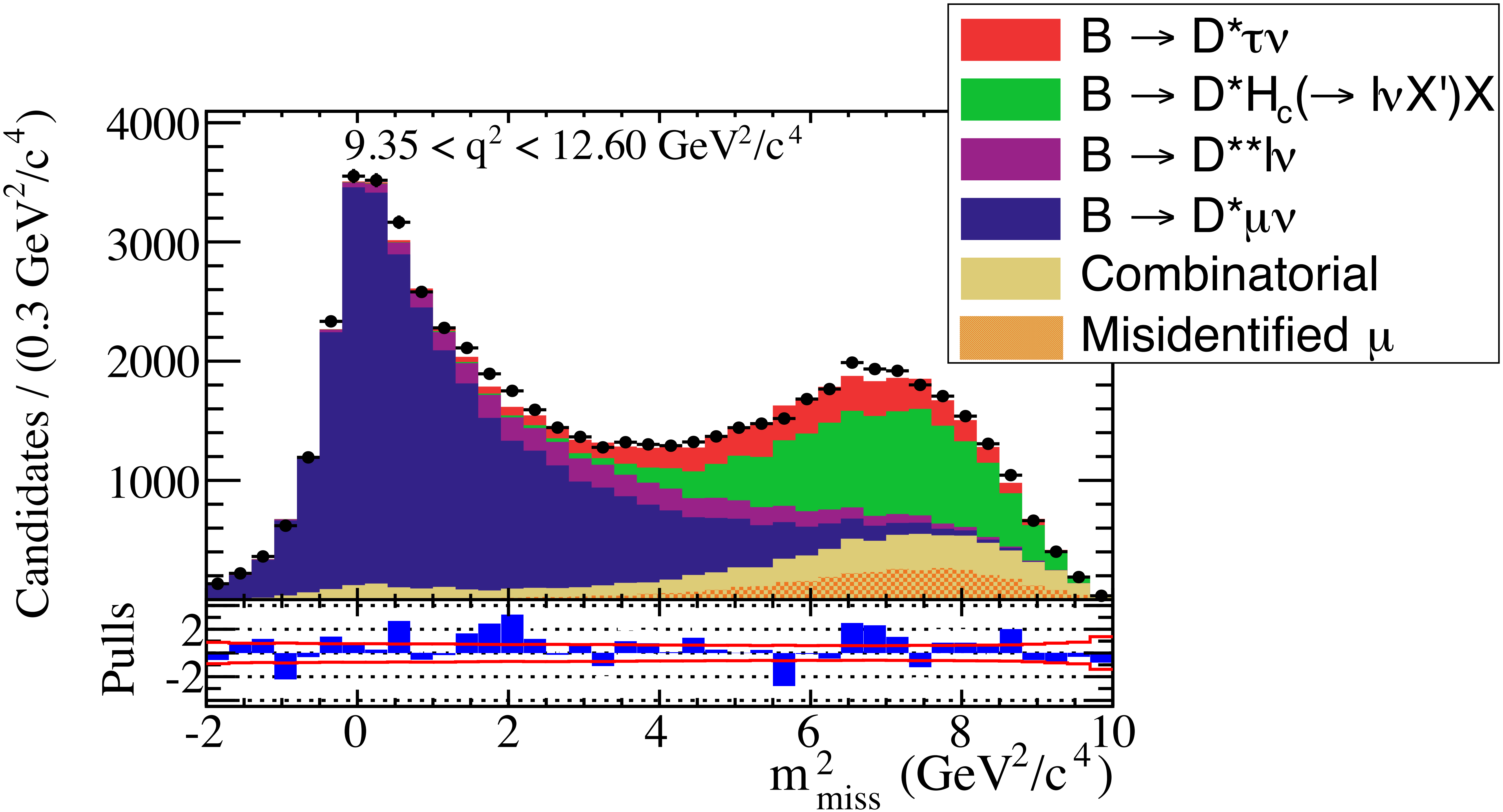
B → D^*D_s → $D^*\mu\nu X$ more problematic

Variables calculated using the following approximation for the B momentum: $p_z = (m_B/m_{vis})p_{z,vis}$

Highest purity q^2 slice

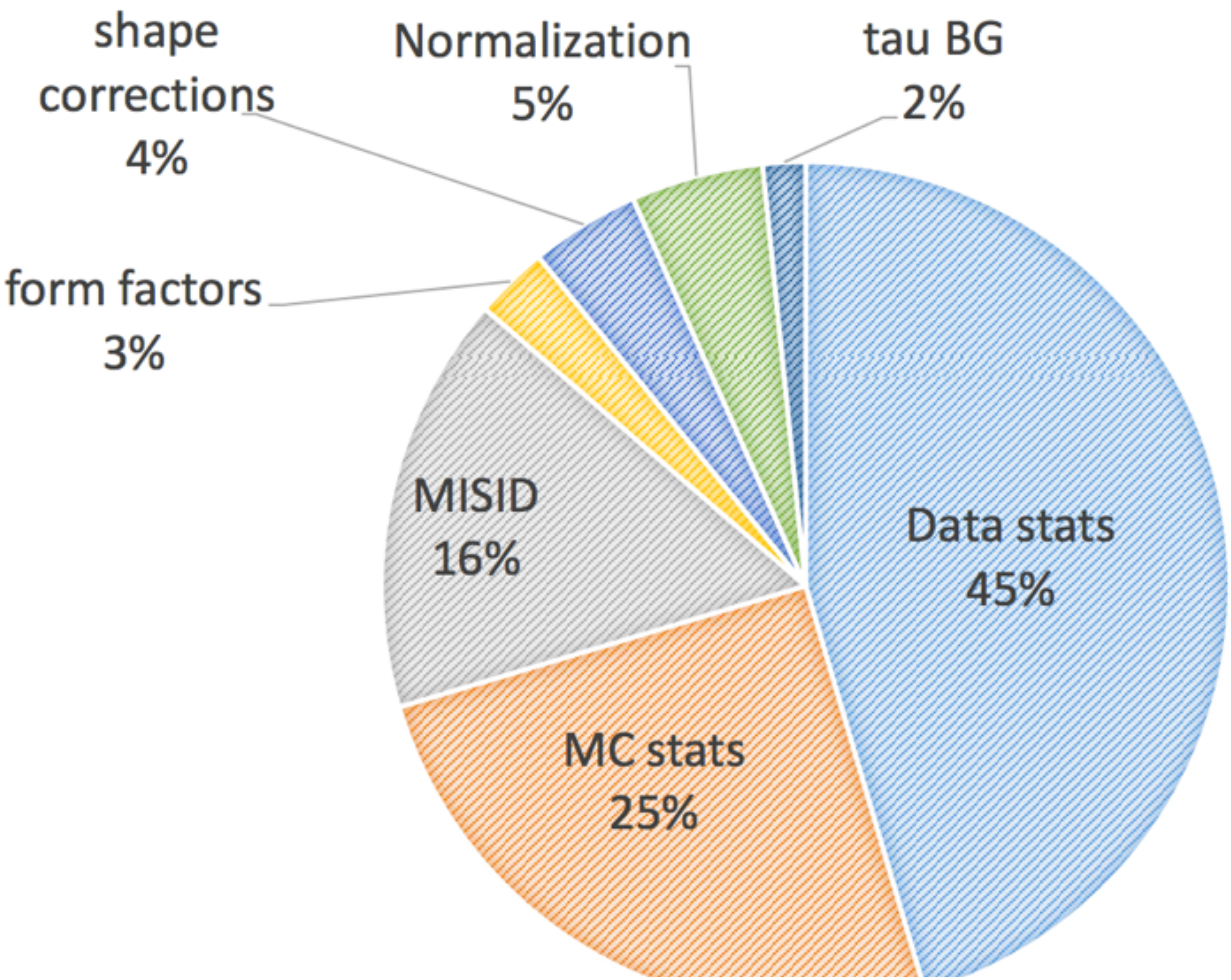


Highest purity q^2 slice



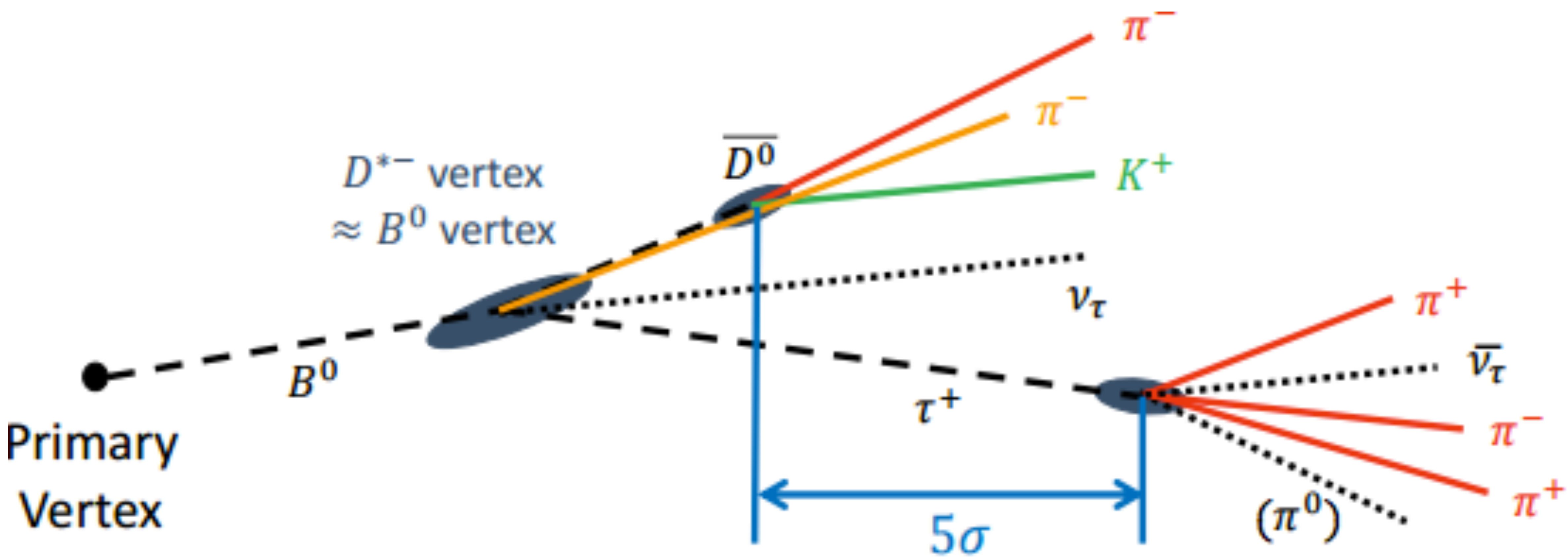
$$R(D^*) = 0.336 \pm 0.027_{stat} \pm 0.030_{syst}$$

LHCb $R(D^*)$ error budget



LHCb future prospects

- In progress: "R" with D^0, D_s, Λ_c, Λ_c^*, J/Ψ, ...
- And with tau $\tau \rightarrow 3\pi\nu X$.



... and $X_u\tau\nu$ decays?

1^{st} and 2^{nd} generation?

arXiv.org > hep-ph > arXiv:1506.01705

Search or

High Energy Physics – Phenomenology

On the breaking of Lepton Flavor Universality in B decays

Admir Greljo, Gino Isidori, David Marzocca

(Submitted on 4 Jun 2015 (v1), last revised 2 Jul 2015 (this version, v2))

In view of recent experimental indications of violations of Lepton Flavor Universality (LFU) in B decays, we analyze constraints and implications of LFU interactions, both using an effective theory approach, and an explicit dynamical model. We show that a simple dynamical model based on a $SU(2)_L$ triplet of massive vector bosons, coupled predominantly to third generation fermions (both quarks and leptons), can significantly improve the description of present data. In particular, the model decreases the tension between data and SM predictions concerning: i) the breaking of τ–μ universality in $B \to D^{(*)}\ell\nu$ decays; ii) the breaking of μ–e universality in $B \to K\ell^+\ell^-$ decays; iii) the difference between exclusive and inclusive determinations of $|V_{cb}|$ and $|V_{ub}|$. The minimal version of the model is in tension with ATLAS and CMS direct searches for the new massive vectors (decaying into $\tau^+\tau^-$ pairs), but this tension can be decreased with additional non-standard degrees of freedom. Further predictions of the model both at low- and high-energies, in view of future high-statistics data, are discussed.

Charged currents. The $b \to c(u)\tau\nu$ charged currents should exhibit a universal enhancement (independent of the hadronic final state). This implies, in particular, $R_{B\tau\nu} = R_D^{\tau/\mu} = R_{D^*}^{\tau/\mu}$. LFU violations between $b \to c(u)\mu\nu$ and $b \to c(u)e\nu$ can be as large as $O(1\%)$. The inclusive $|V_{cb}|$ and $|V_{ub}|$ determinations are enhanced over the exclusive ones because of the τ contamination in the corresponding samples.

Experimental status/prospects?

- Best measurement from Belle[1]

$$R_{e\mu} = 0.995 \pm 0.022_{stat} \pm 0.039_{syst}$$

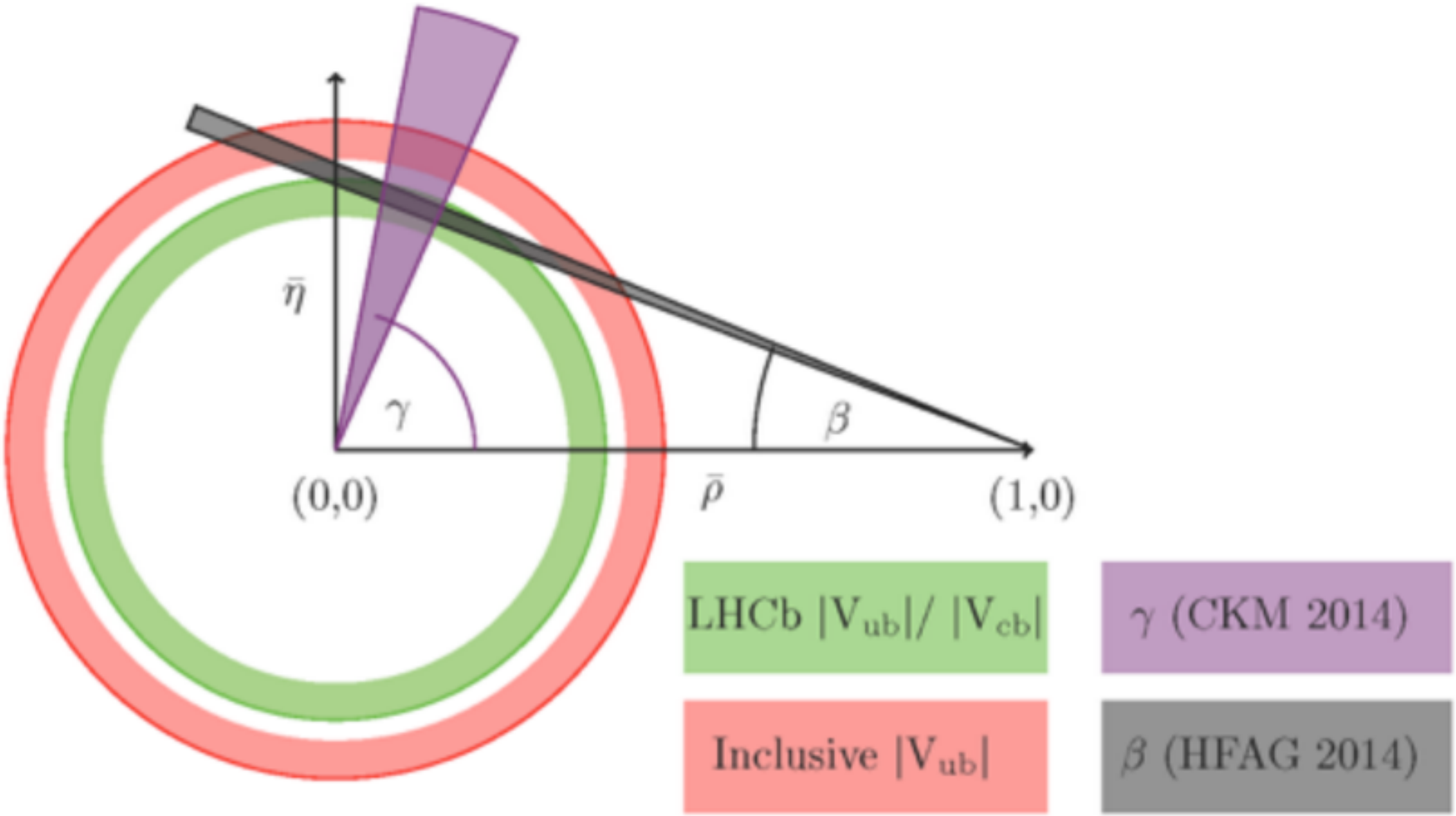
- LHCb challenge: control of electron efficiency
- Plan to measure:

$$R_{e\mu} = \frac{B \to D^{(*)} e\nu \,/\, B \to D^{(*)} \mu\nu}{D^0 \to K e\nu \,/\, D^0 \to K \mu\nu}$$

Tentative goal with Run-I data: $\delta R_{e\mu} \approx$ few x 10^{-3}

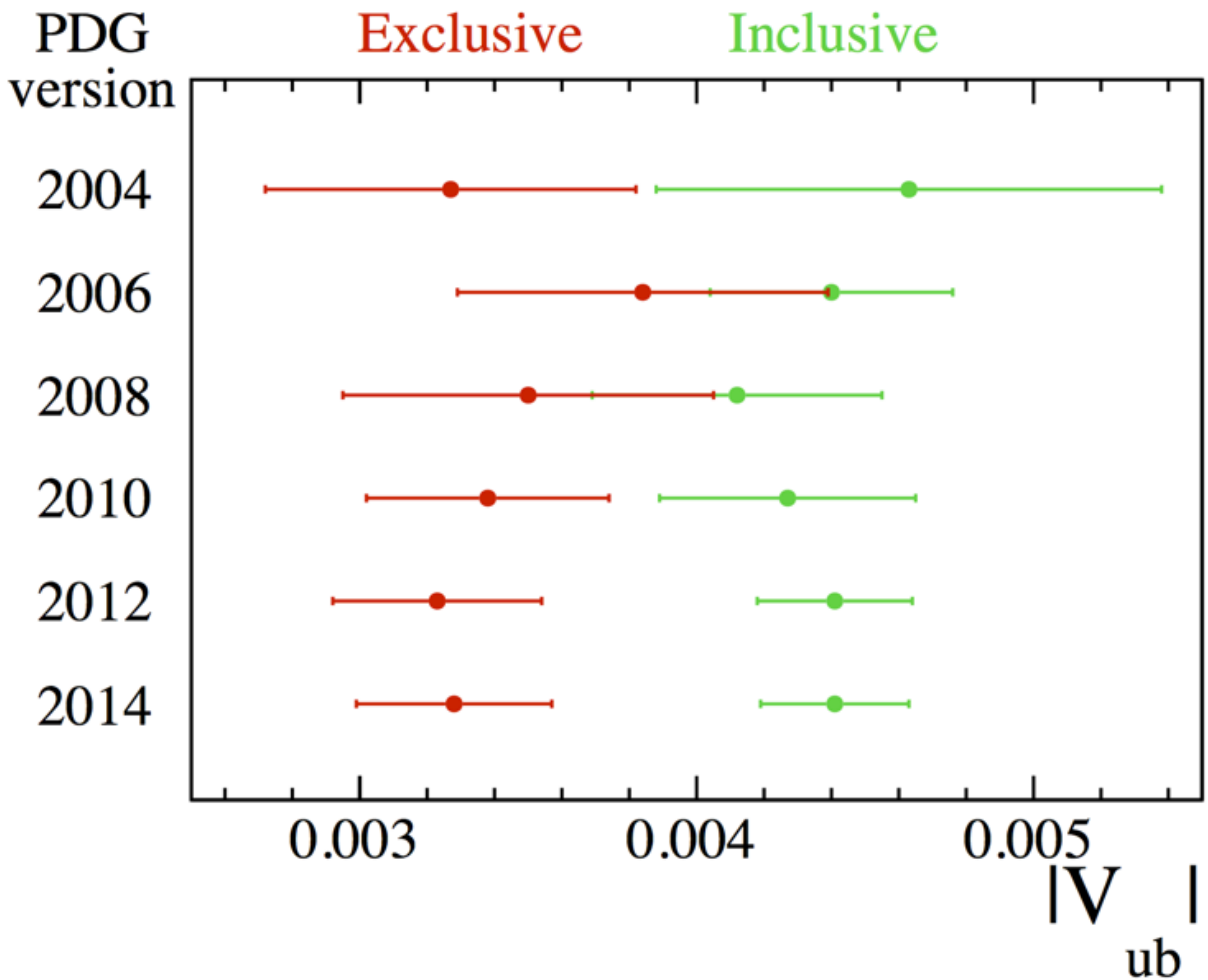
1. Belle, 1510.03657 (2015)

CKM metrology

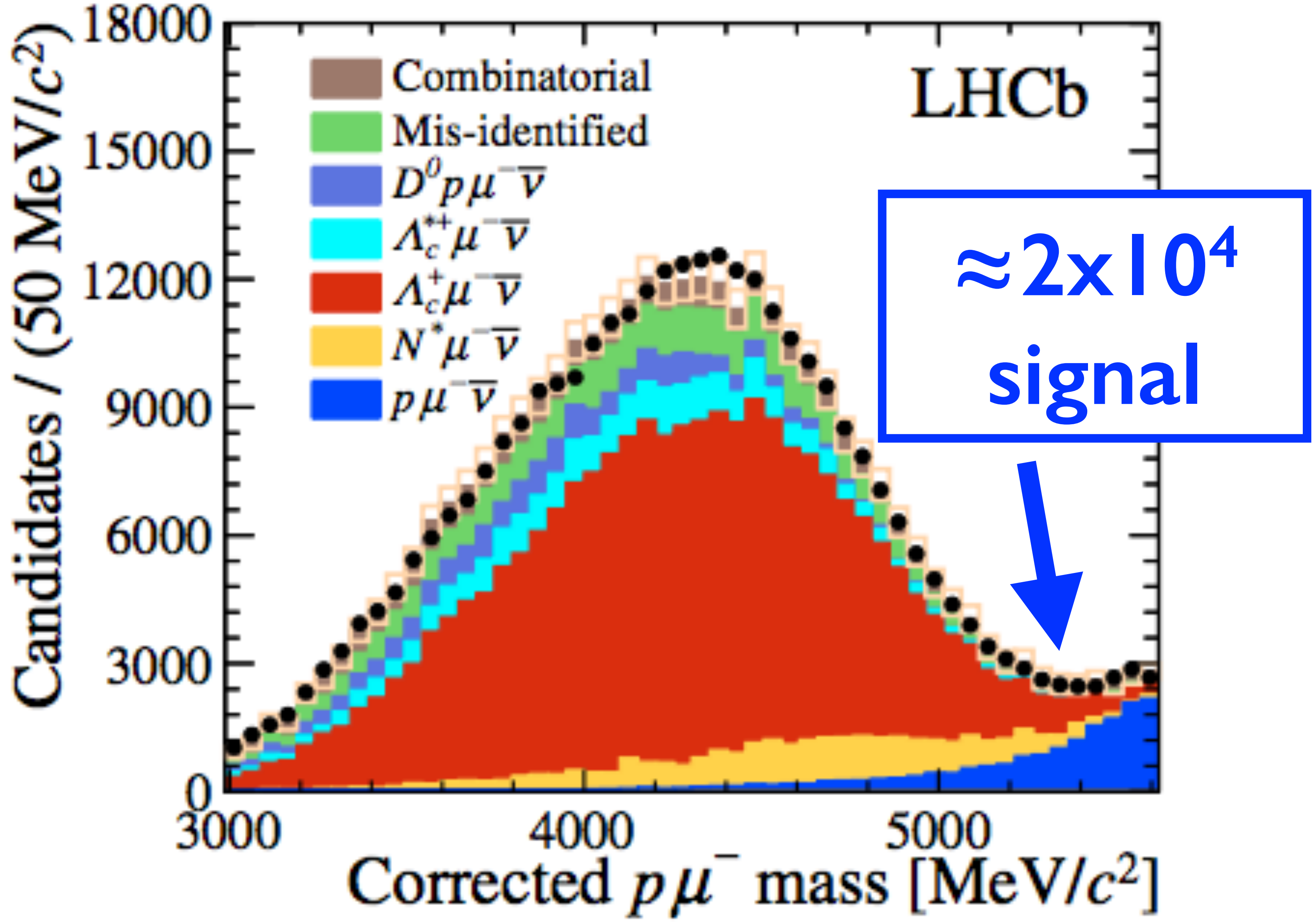


Need to better understand $|V_{ub}|$ (and $|V_{cb}|$)

The $|V_{ub}|$ saga


PDG version
Exclusive
Inclusive
2004
2006
2008
2010
2012
2014
0.003
0.004
0.005
|V_ub|

LHCb $\Lambda_b \to p\mu\nu$

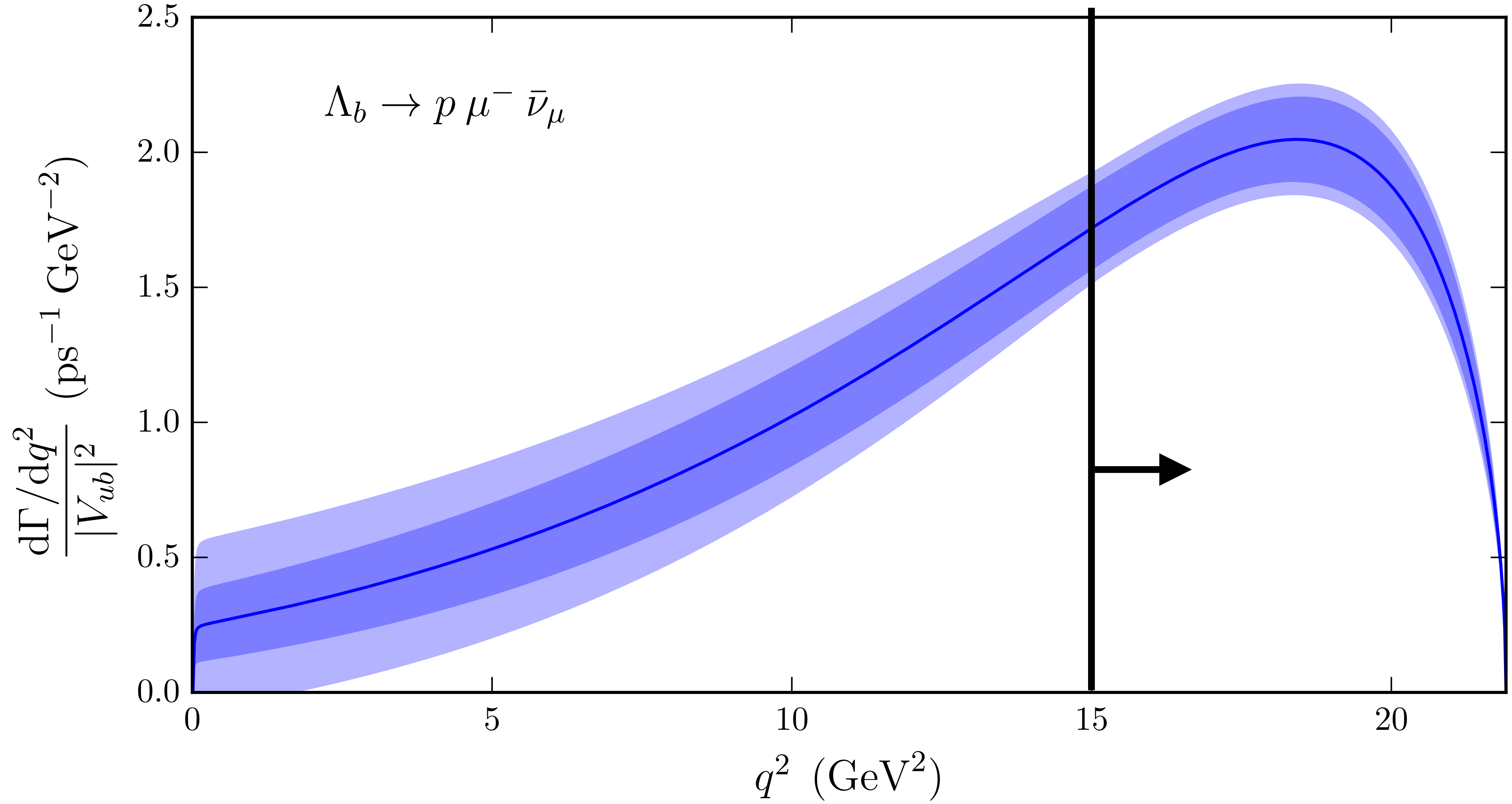


In restricted* q^2 range:

$$\frac{\mathcal{B}(\Lambda_b \to p\mu\nu)}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)} = (1.00 \pm 0.04_{\rm stat} \pm 0.08_{\rm syst}) \times 10^{-2}$$

*q^2>7(15) GeV^2 for $p\mu\nu(\Lambda_c\mu\nu)$

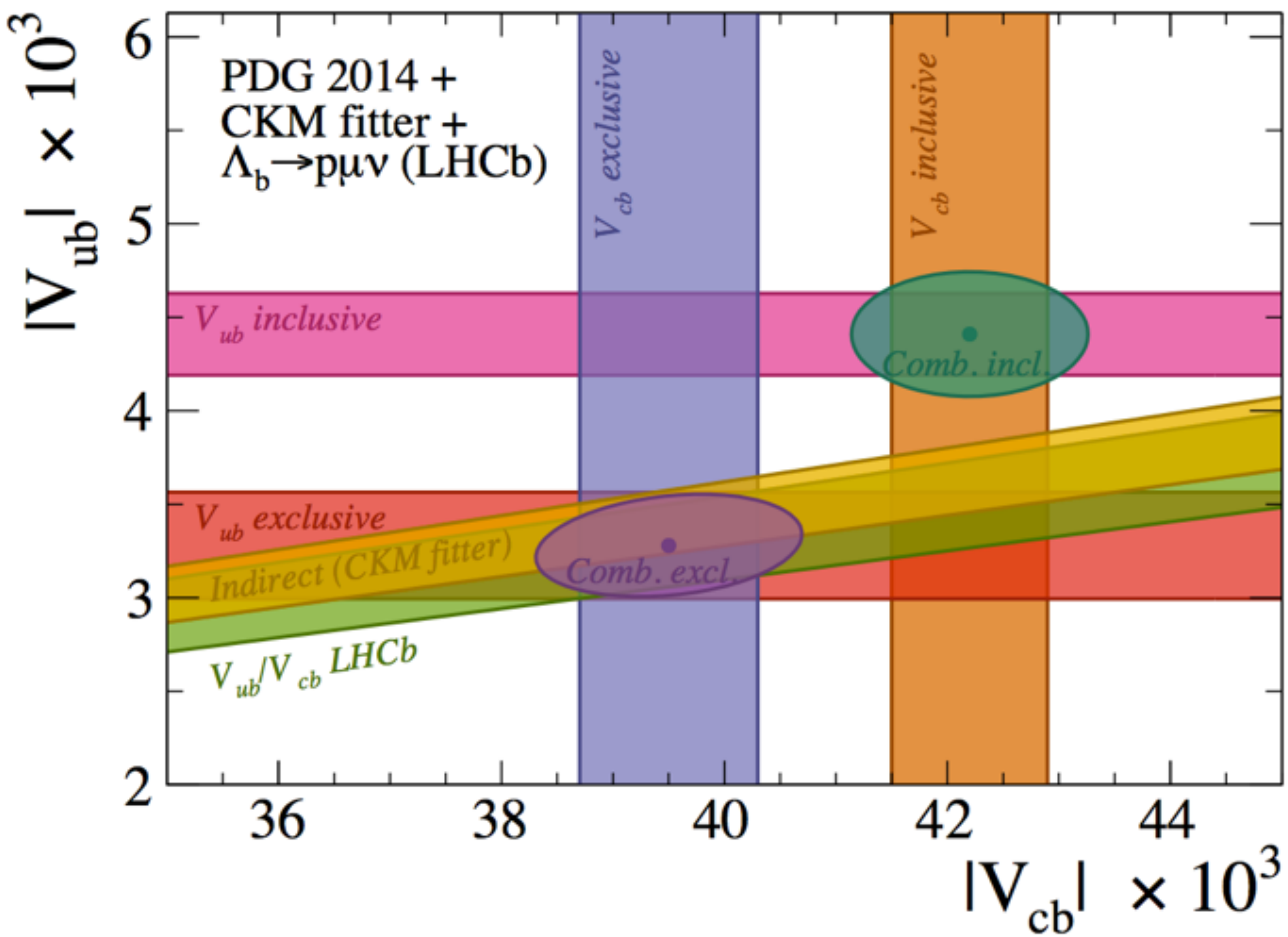
Lattice[1] $\Lambda_b \to p\mu\nu$



$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004_{\mathrm{expt}} \pm 0.004_{\mathrm{latt}}$$

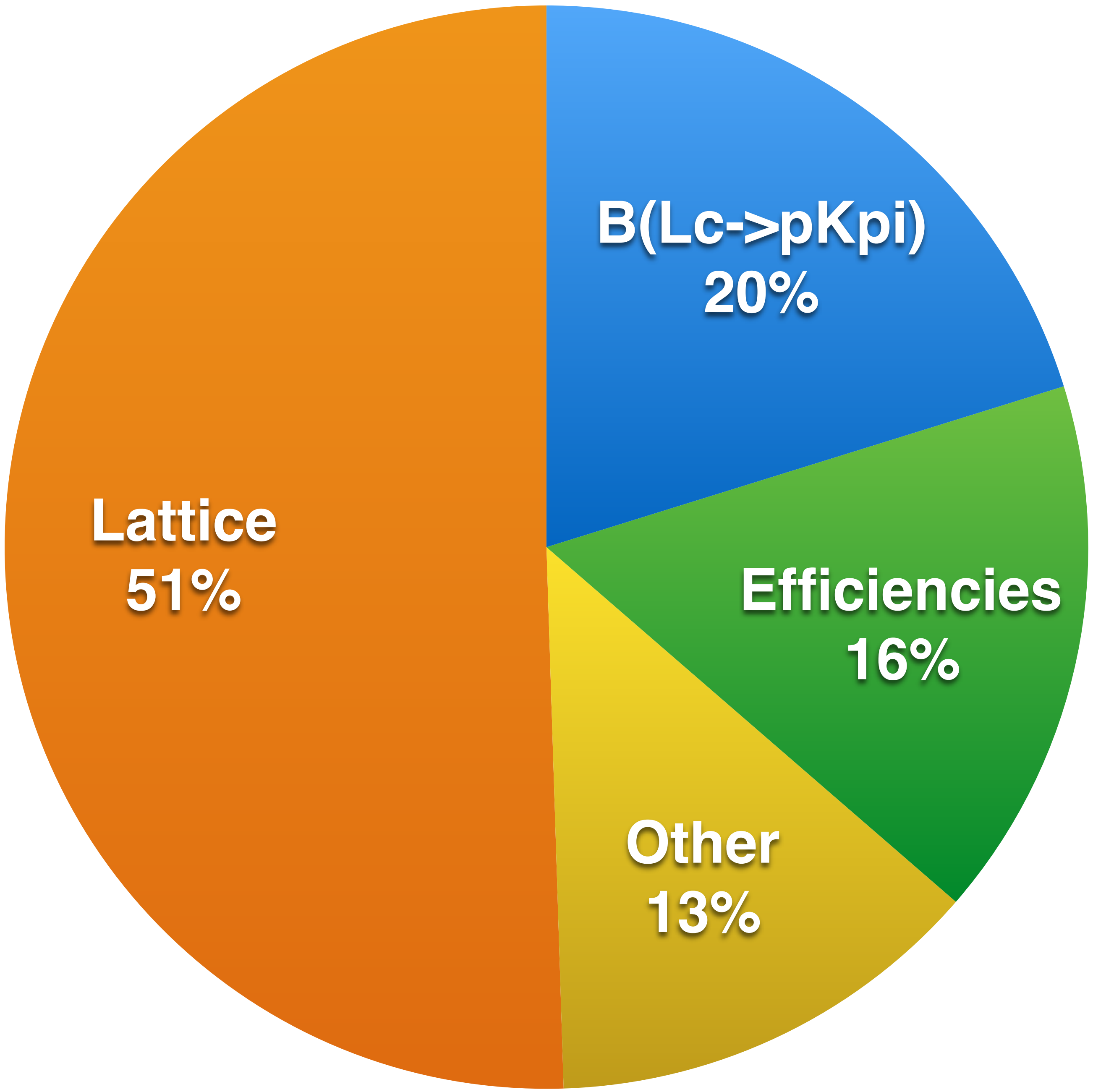
[1] W. Detmold, C. Lehner, S. Meinel, 1503.01421 (2015)

State of the art



Much more to understand...

$|V_{ub}|$ (pμν) error budget

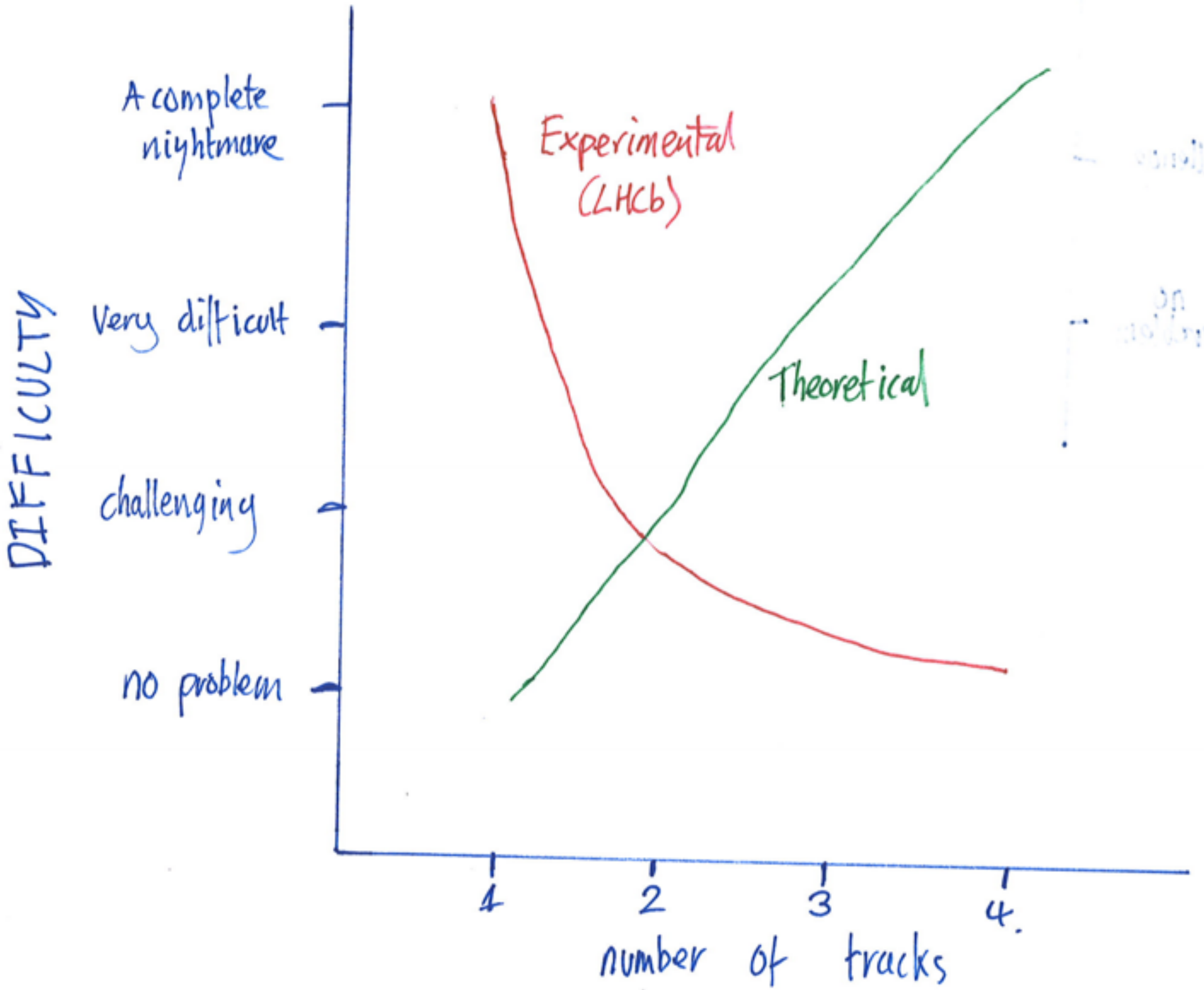


Not* much more that LHCb can do here....

Area of wedges proportional to error squared

*Maybe better control of lattice uncertainties with q^2 dependent measurement?

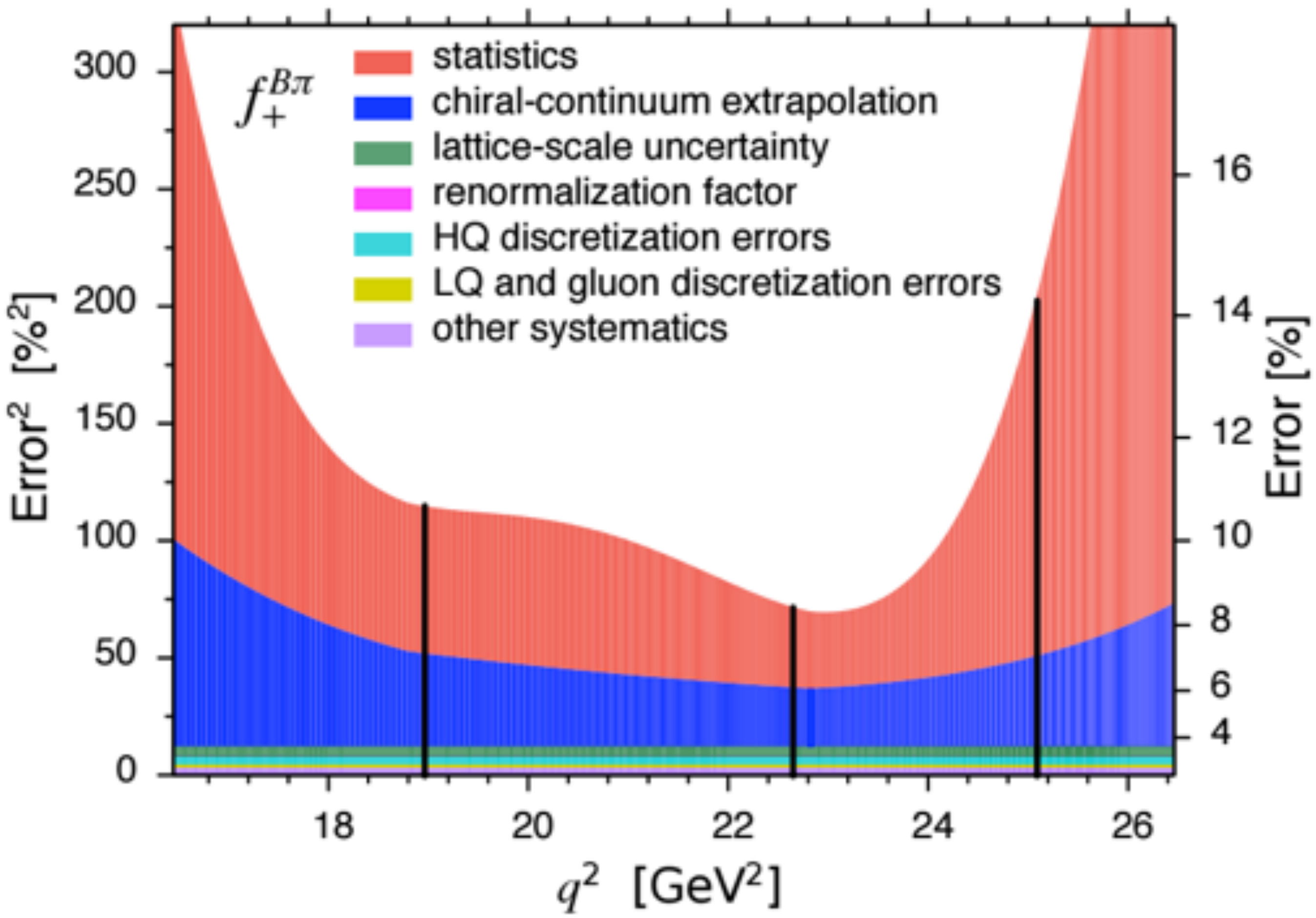
$|V_{ub}|$ with other modes?

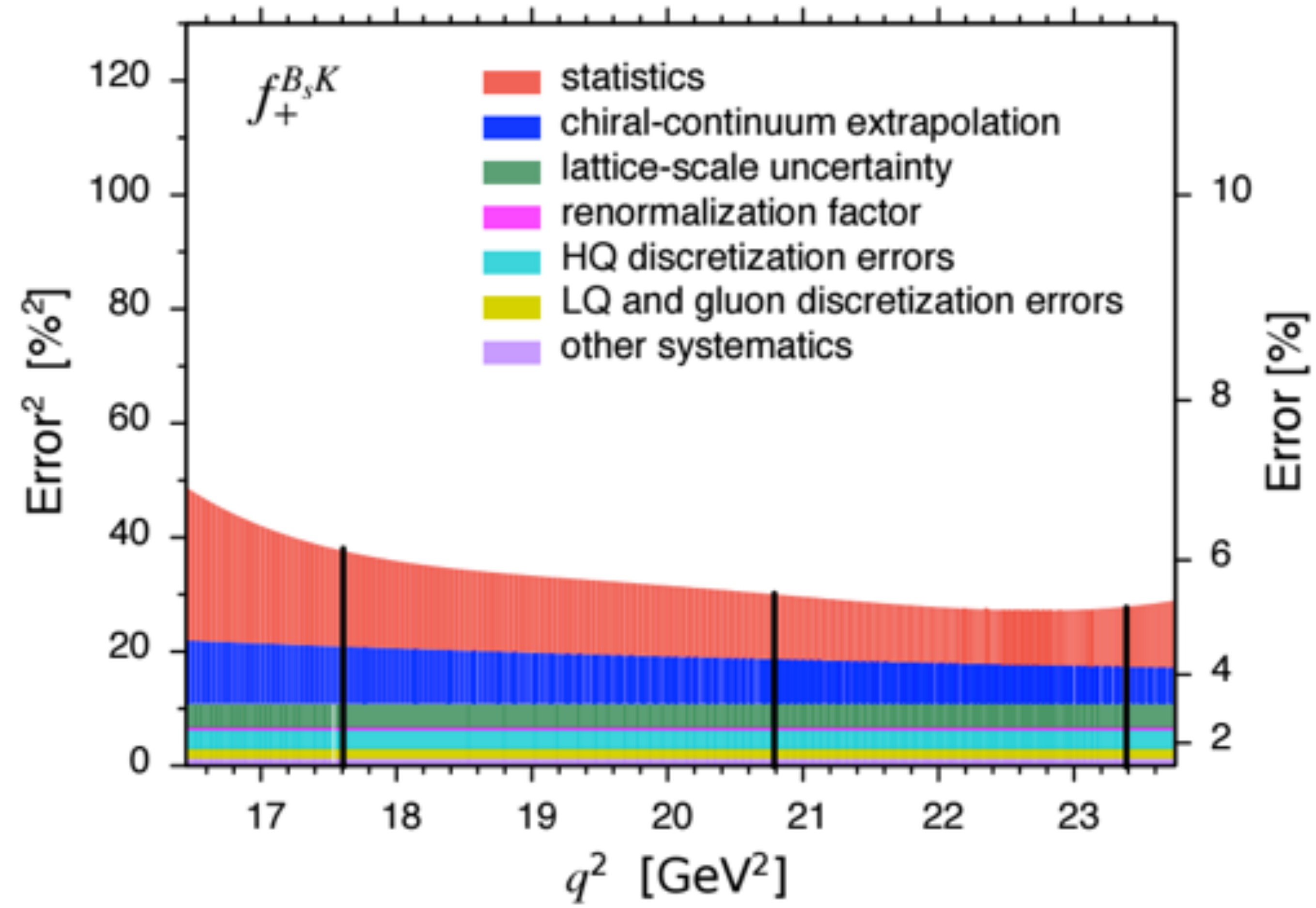


Thanks to P. Owen for the sketch!

$B_s \to K\mu\nu$ (lattice)

plots from RBC/UKQCD group, arXiv:1501.05373





LHCb should measure $B_s \to K\mu\nu$ / $B_s \to D_s\mu\nu$...

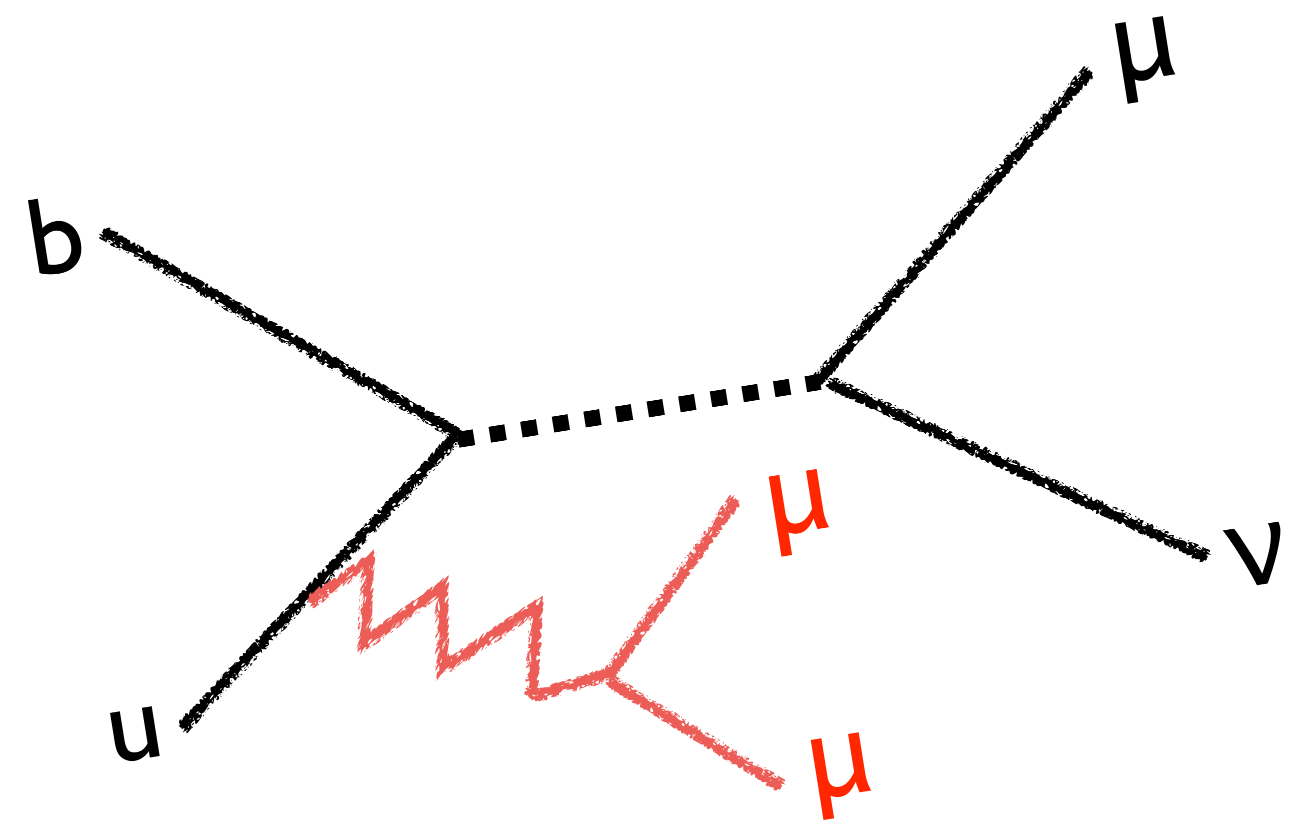
$B_s \to K\mu\nu$ (LHCb)

	$\Lambda_b \to p\mu\nu$	$B_s \to K\mu\nu$
Lattice	5%	3%
f_{prod}	20%	10%
BF	4×10^{-4}	1×10^{-4}
$B(X_c)$ err.	$\approx$5%	3%
Bgds.	Λ_c	Λ_c, D_s, D^+,D^-

Experimentally more challenging,
but 5% uncertainty possible...

Other ideas

- $b \to \mu\mu\mu\nu$, $b \to \phi\mu\nu$
- $b \to l\nu KKX$ decays[1]
- $b \to pp l\nu$ decays
- B_c V_{ub} decays
- ....



1. Bigi, http://arxiv.org/abs/1507.01842v3. If we see these modes, can they help to understand $|V_{ub}|_{incl}$ - $|V_{ub}|_{excl}$?

Conclusion

- How much theory interest in improved a_{sl}?
- Focus on which modes to understand R(D)?
- Likewise for $|V_{ub}|$?