

Search for new physics in semileptonic B-decays

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on behalf of the LHCb collaboration

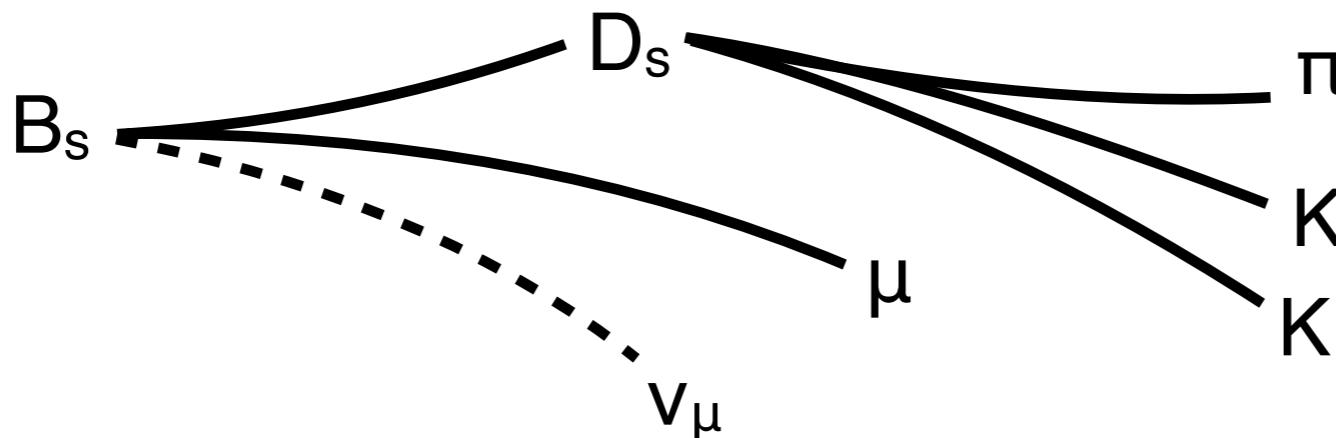
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5 August 2016



Semileptonic B-decays

B-decays with a missing daughter: neutrino

- Large statistics: high precision
- Neutrinos: partially reconstructed decays

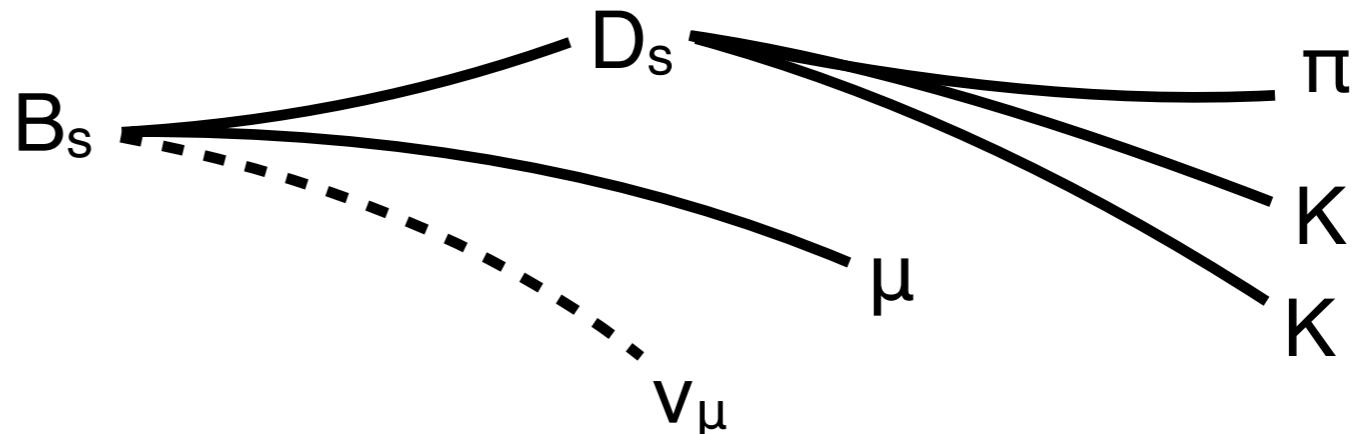


Semileptonic B-decays

Many interesting analyses:

- Lepton universality
- CP violation in mixing
- CKM matrix elements
- Production cross-sections

This talk



Lepton universality: $R(D^*)$

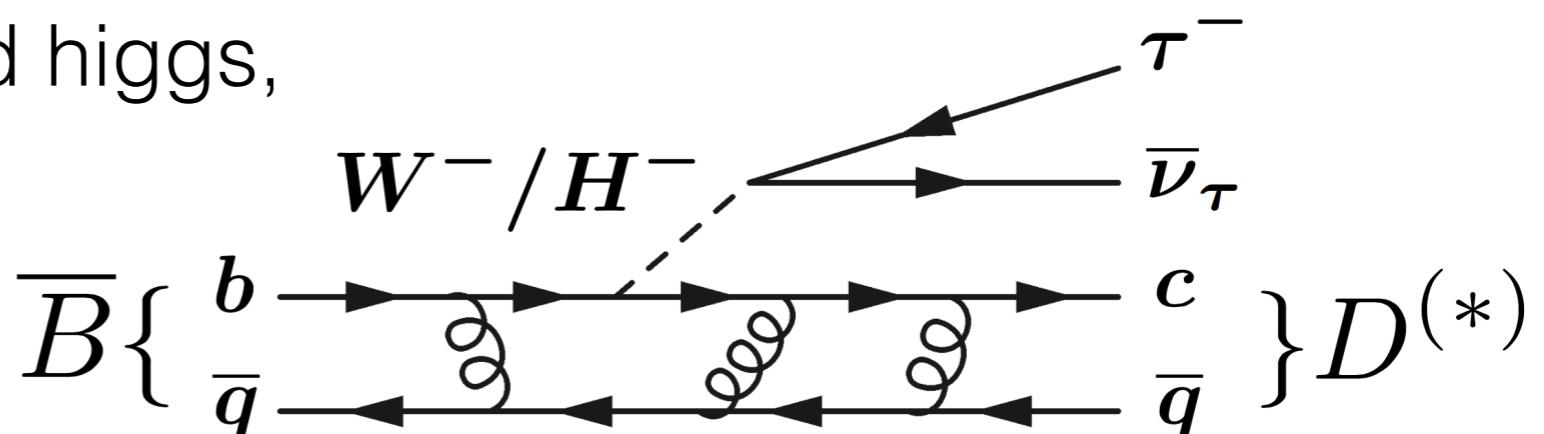
- Measuring the ratio of branching fractions:

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

- Standard Model prediction is theoretically clean:

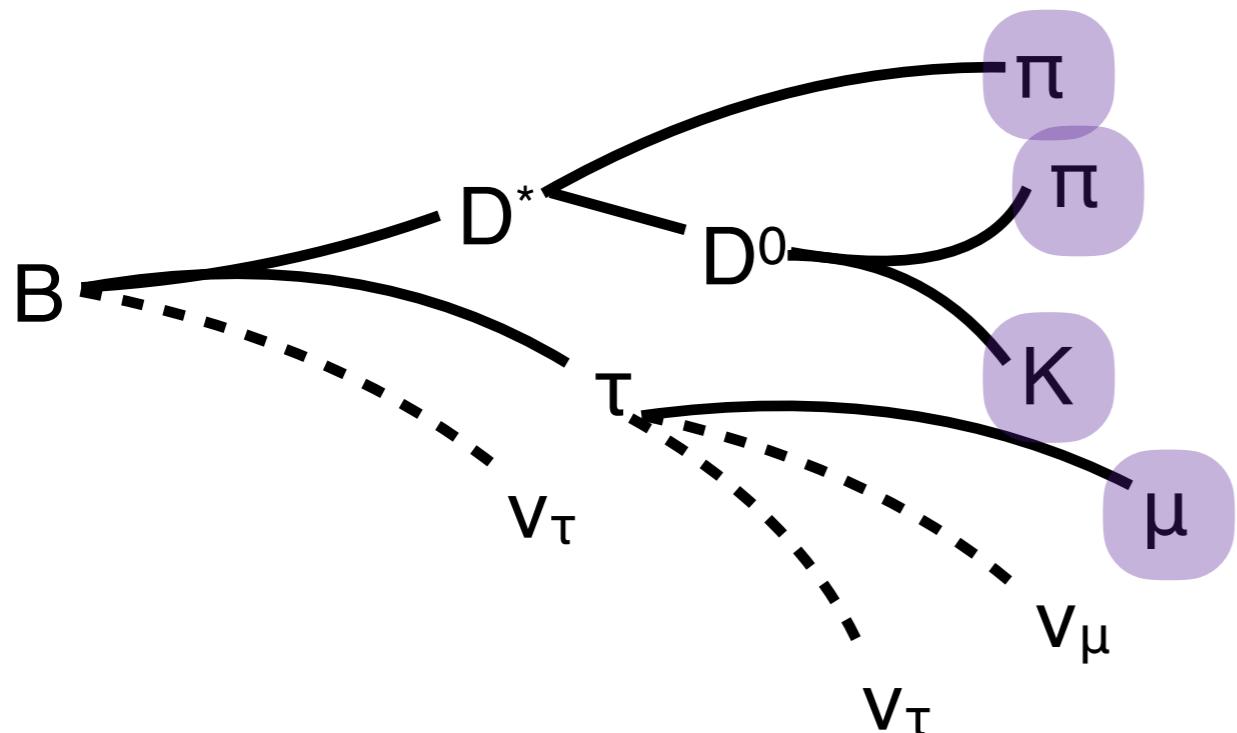
$R(D^*) = 0.252 \pm 0.003$ [PRD 85 \(2012\) 094025](#)

- Tree-level processes sensitive to new physics: charged higgs, leptoquarks

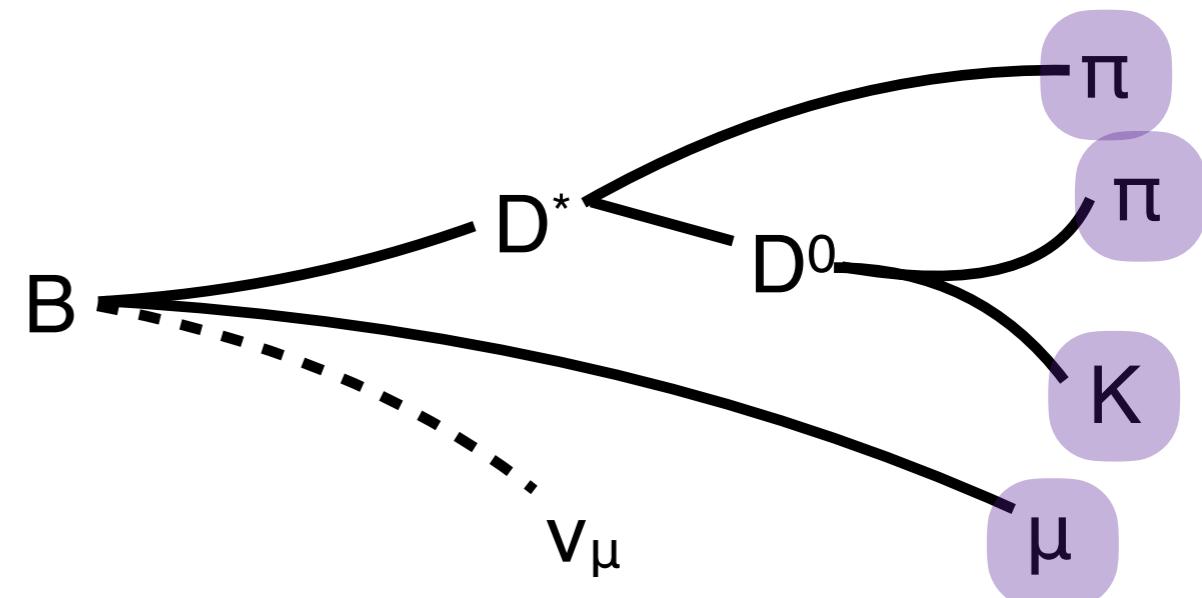


Measurement in LHCb

signal:



normalization:



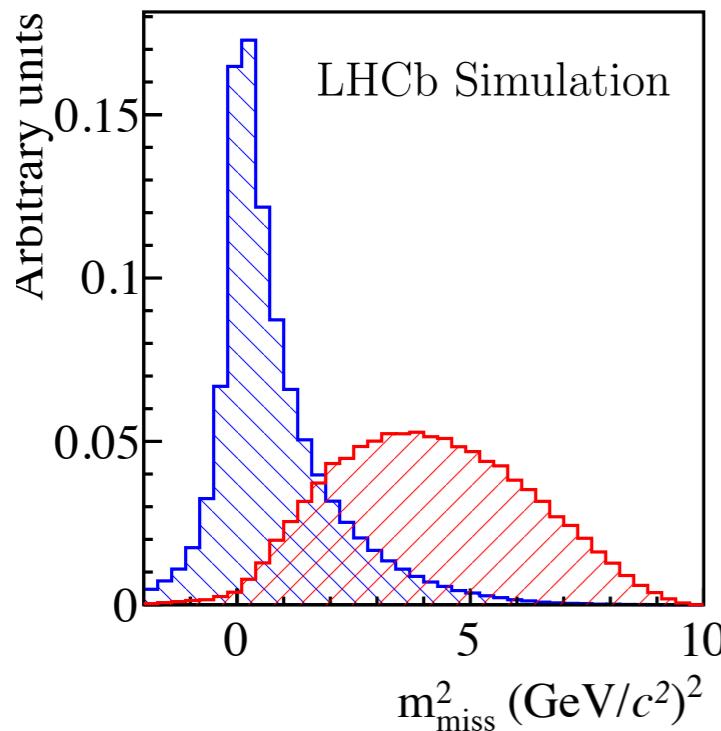
Signal and normalization channel have same visible final state

Fit variables

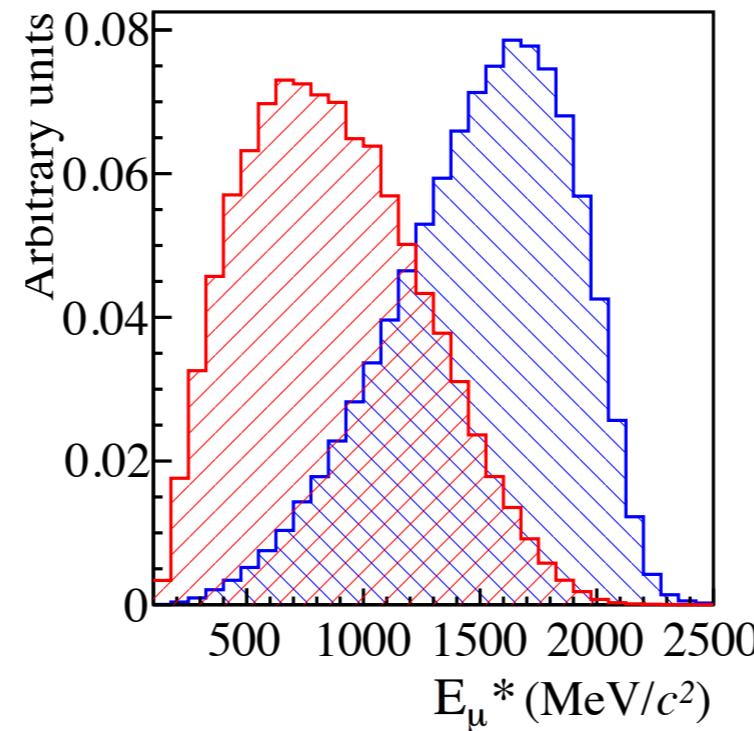
Kinematics between two channels are very different:

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)$$

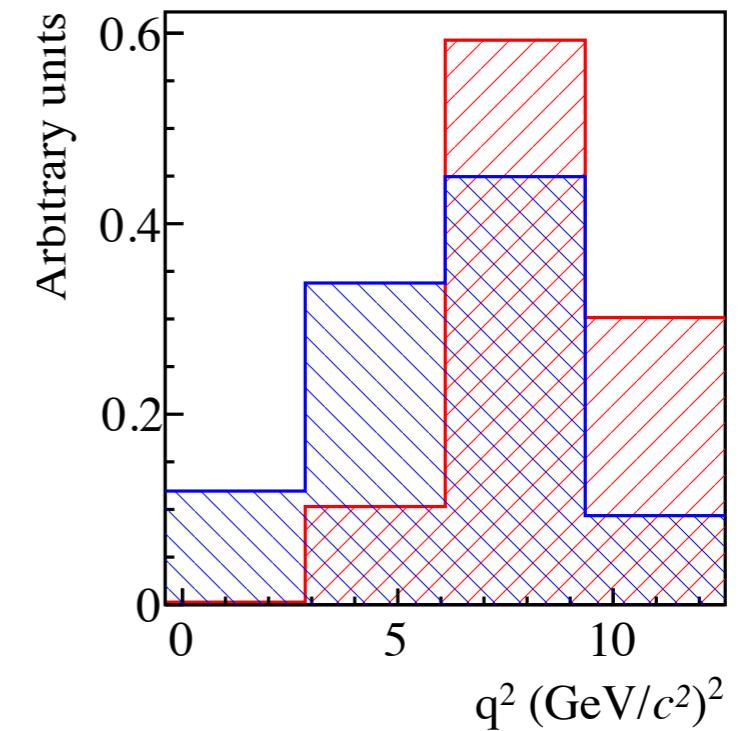
$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)$$



missing mass:
calculated using the
B flight direction



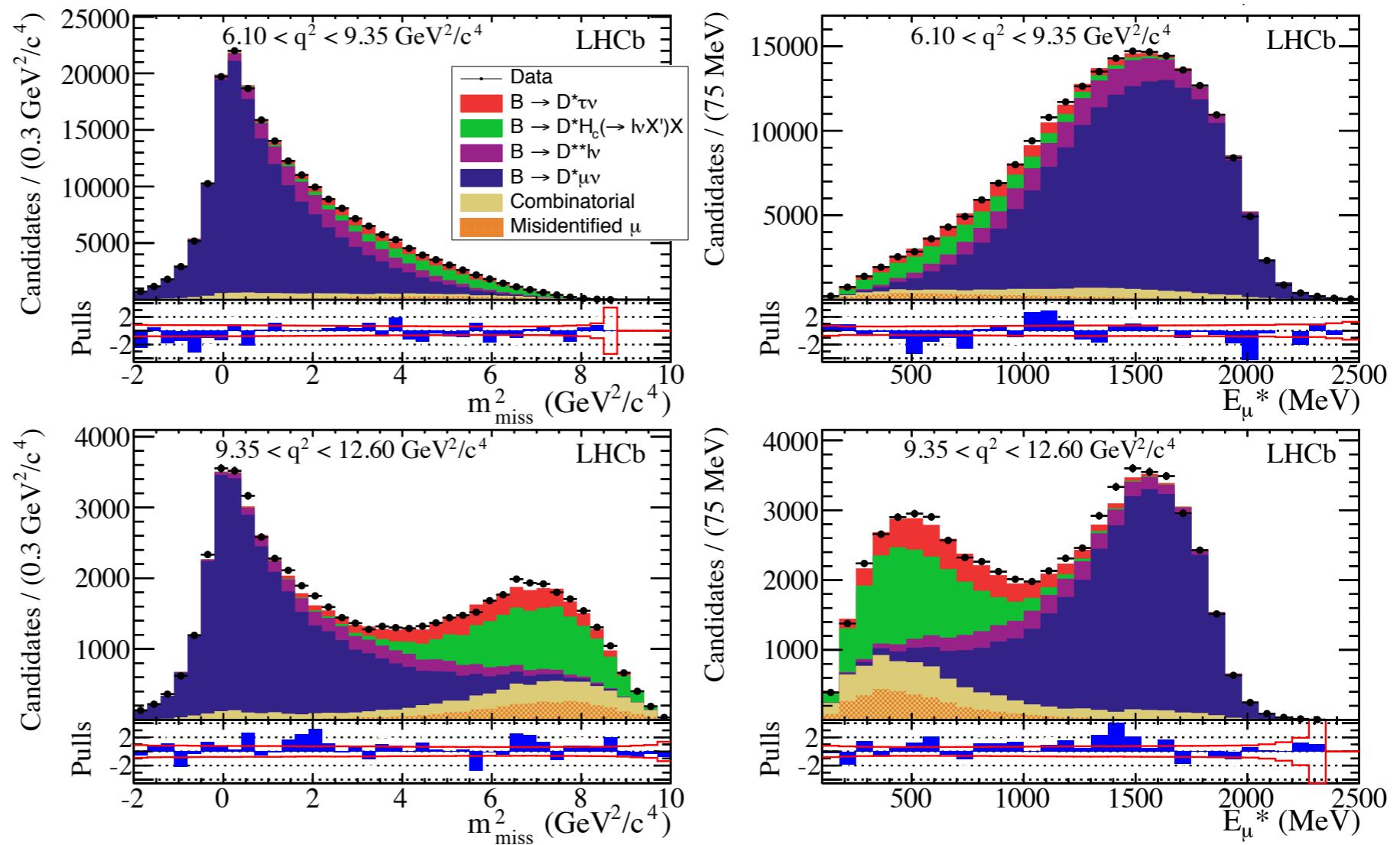
muon energy in
center-of-mass



q^2 : 4-momentum
transfer of lepton
system

Fits in highest q^2 bins

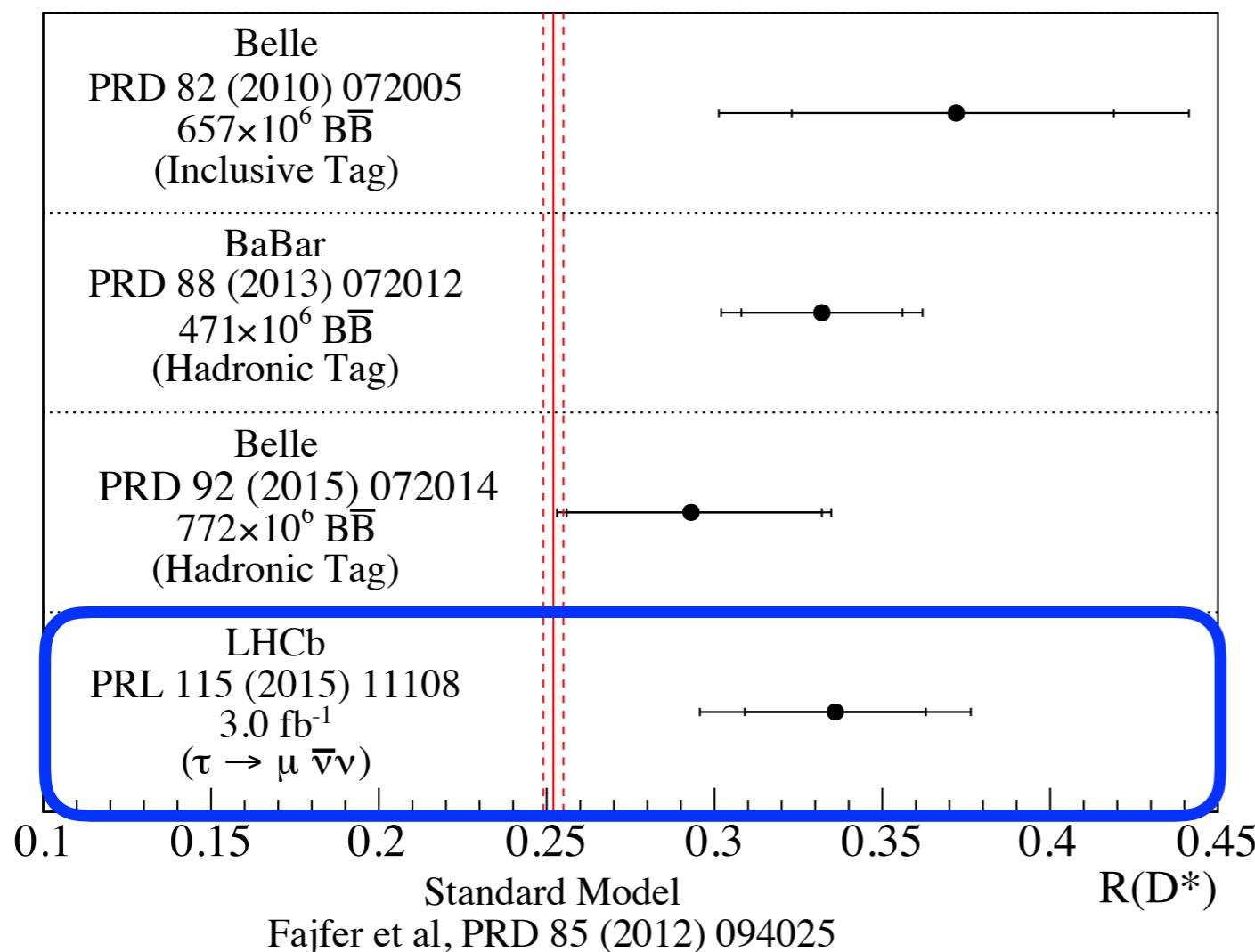
- Fits performed using three-dimensional templates
- Projections in m_{miss}^2 and E_μ^* in bins of q^2
- Signal most visible in high q^2 bin



PRL 115 (2015) 111803

Results

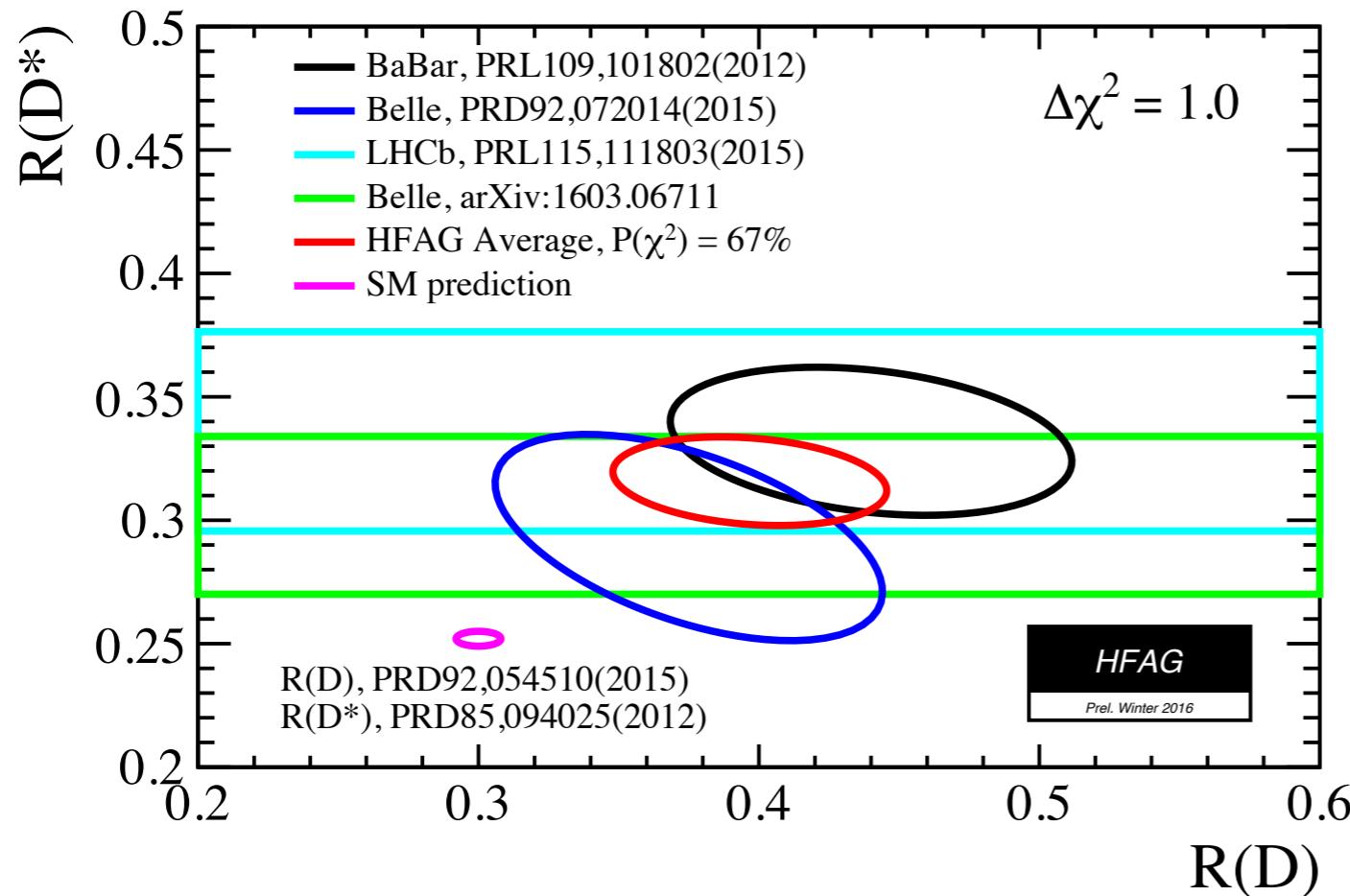
$$\mathcal{R}(D^*) = 0.336 \pm 0.027(\text{stat}) \pm 0.030(\text{syst}) \quad \underline{\text{PRL 115 (2015) 111803}}$$



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

Good consistency
between experiments

Combined $R(D)$ vs. $R(D^*)$



4.0 σ tension
with SM

Prospects for analyses in LHCb:

- analysis of $R(D^*)$ is extended to $R(D)$ vs. $R(D^*)$
- hadronic $R(D^*)$, $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$
- other hadron species, like Λ_c , B_c , B_s

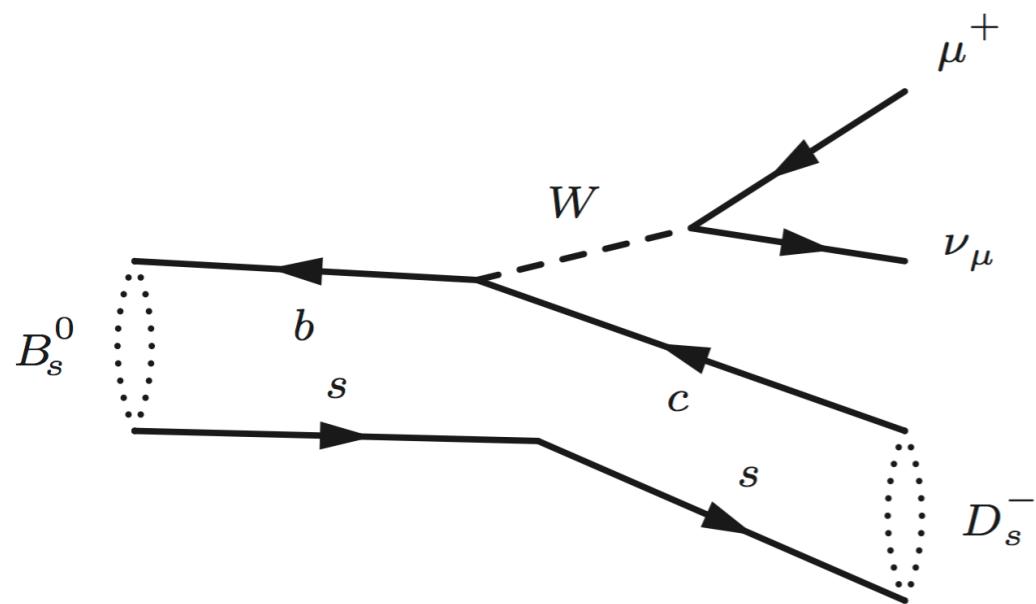
CP violation in mixing

$$\mathcal{P}(B_q \rightarrow \bar{B}_q) \neq \mathcal{P}(\bar{B}_q \rightarrow B_q)$$

Flavour specific asymmetry:

$$a_{\text{fs}} = \frac{\Gamma(\bar{B}_q \rightarrow B_q \rightarrow f) - \Gamma(B_q \rightarrow \bar{B}_q \rightarrow \bar{f})}{\Gamma(\bar{B}_q \rightarrow B_q \rightarrow f) + \Gamma(B_q \rightarrow \bar{B}_q \rightarrow \bar{f})}$$

Semileptonic decays are flavour-specific:



a_{sl} is very small in SM

$$a_{\text{sl}}^s = (2.22 \pm 0.27) \times 10^{-5} \text{ for } B_s^0$$
$$a_{\text{sl}}^d = (-4.7 \pm 0.6) \times 10^{-4} \text{ for } B^0$$

Artuso, Borissov, Lenz [arXiv:1511.09466](https://arxiv.org/abs/1511.09466)

How to measure a_{sl}^s

Looking at the decay: $B_s \rightarrow D_s (\rightarrow K K \pi) \mu \nu_\mu$

$$\frac{a_{\text{sl}}^s}{2} = \frac{1}{1 - f_{\text{bkg}}} (A_{\text{raw}} - A_{\text{det}} - f_{\text{bkg}} A_{\text{bkg}})$$

Fit D_s candidates:

$$A_{\text{raw}} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-)}{N(D_s^- \mu^+) + N(D_s^+ \mu^-)}$$

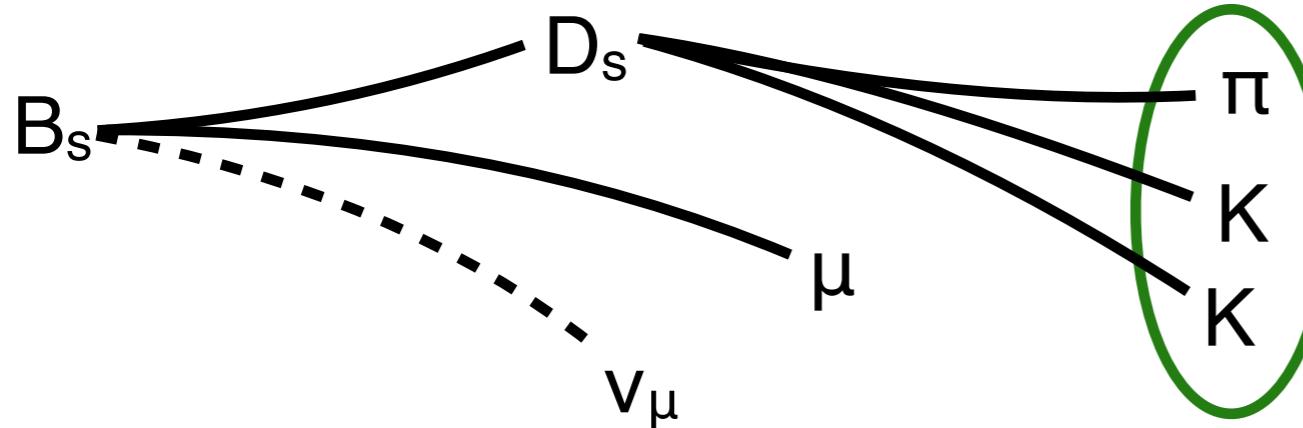
Correct for:

- detection asymmetries:

$$A_{\text{det}} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})}$$

- background

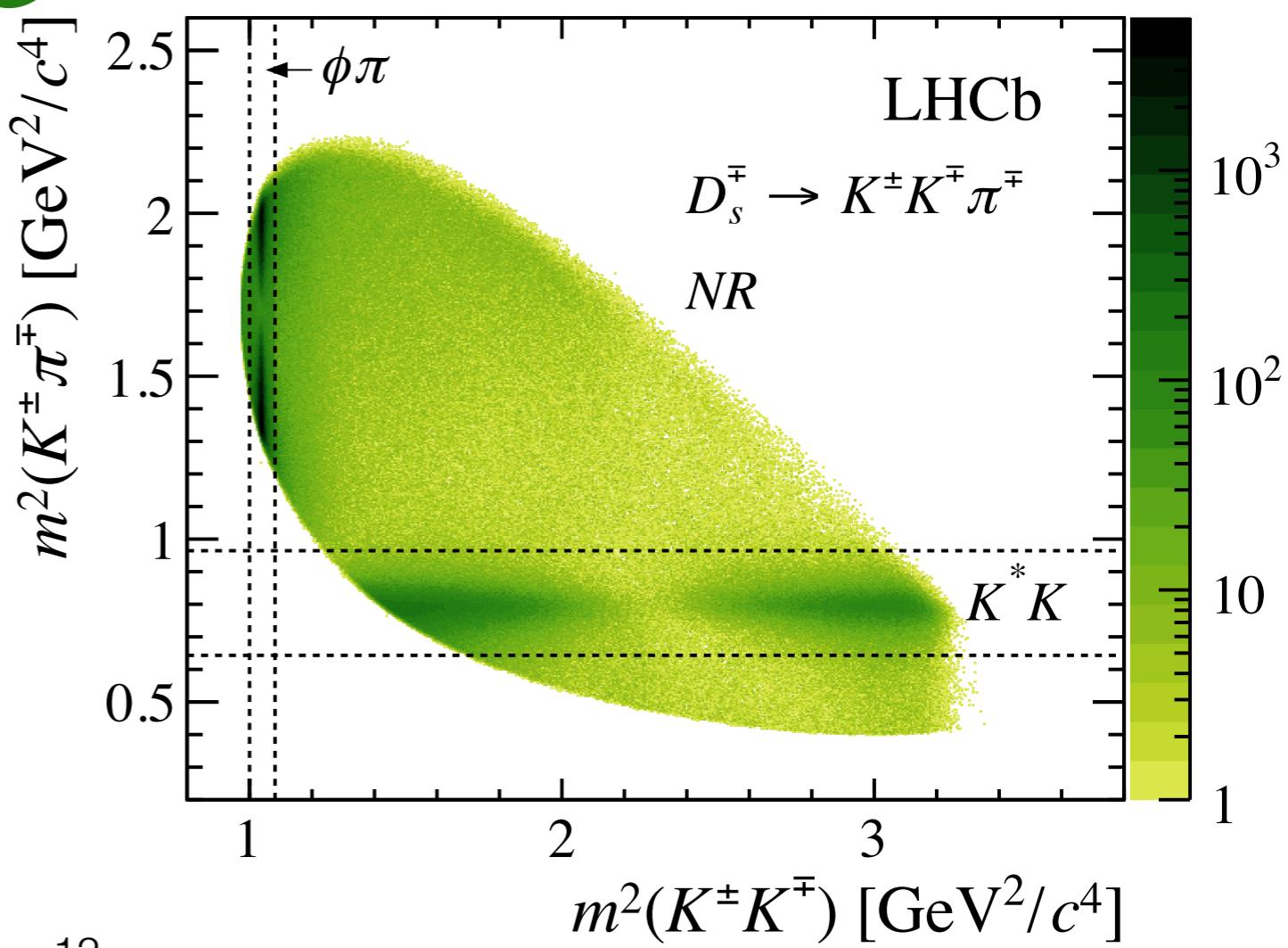
Selecting D_s



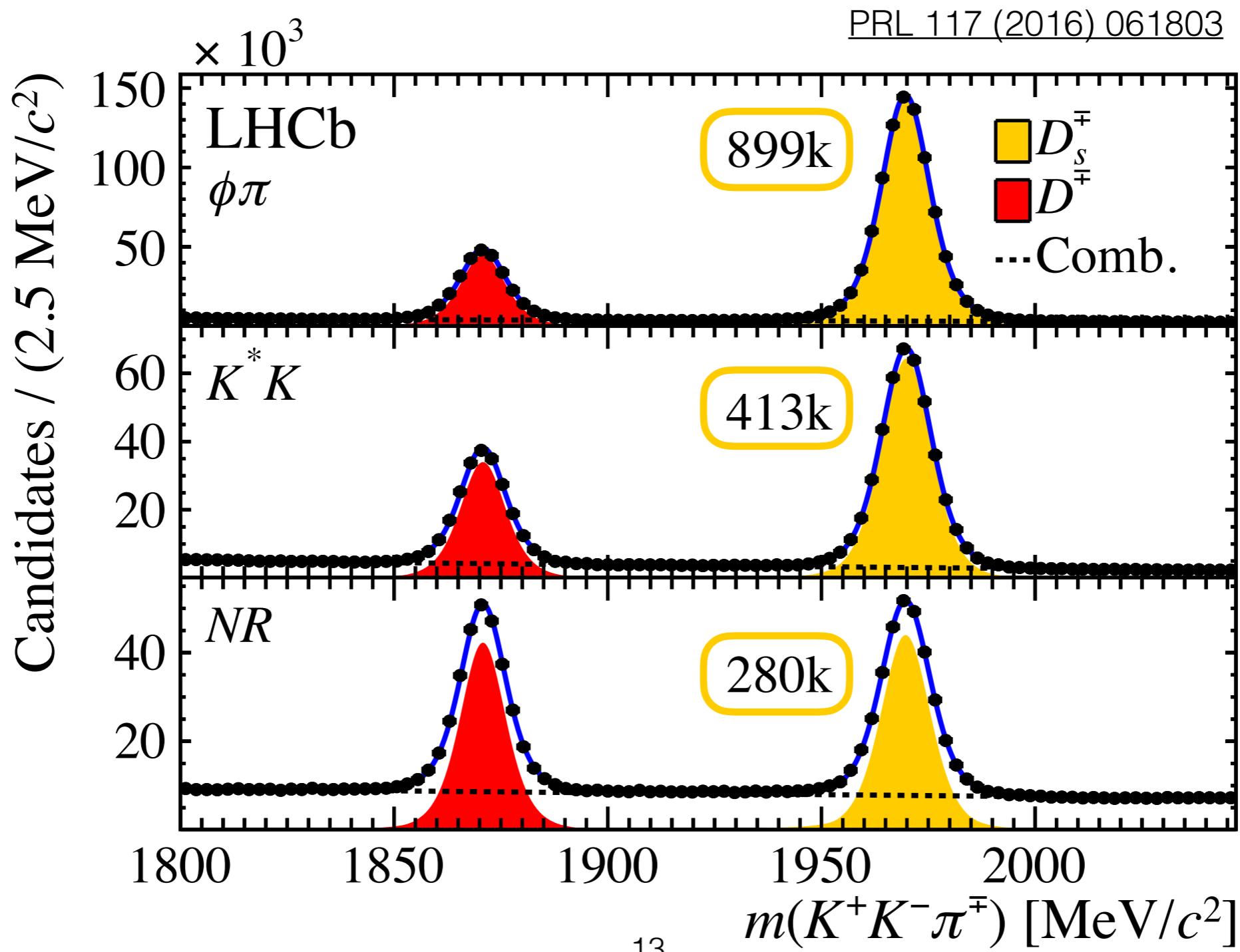
PRL 117 (2016) 061803

Three regions:

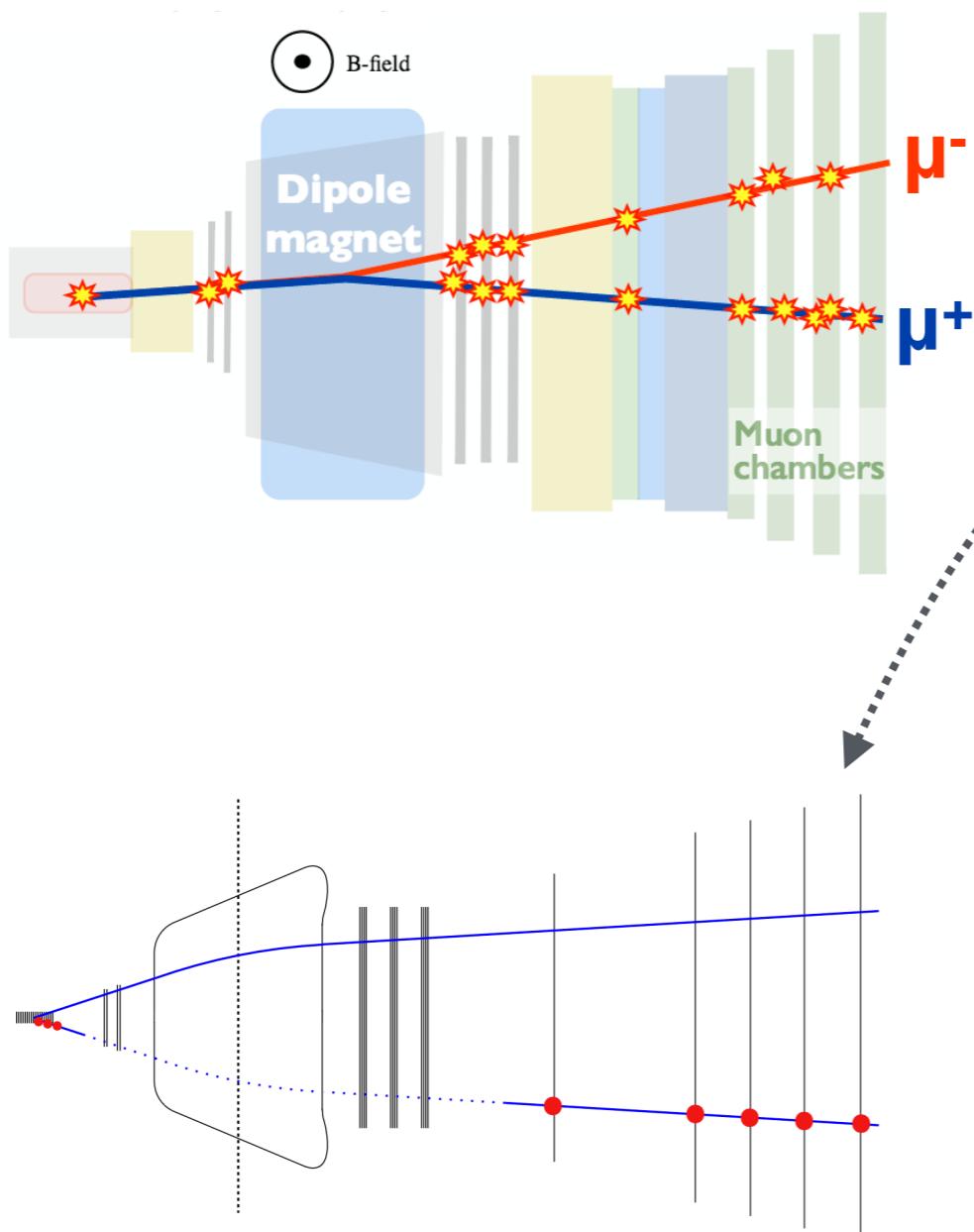
- different selection
- different backgrounds
- same methods



Signal Extraction

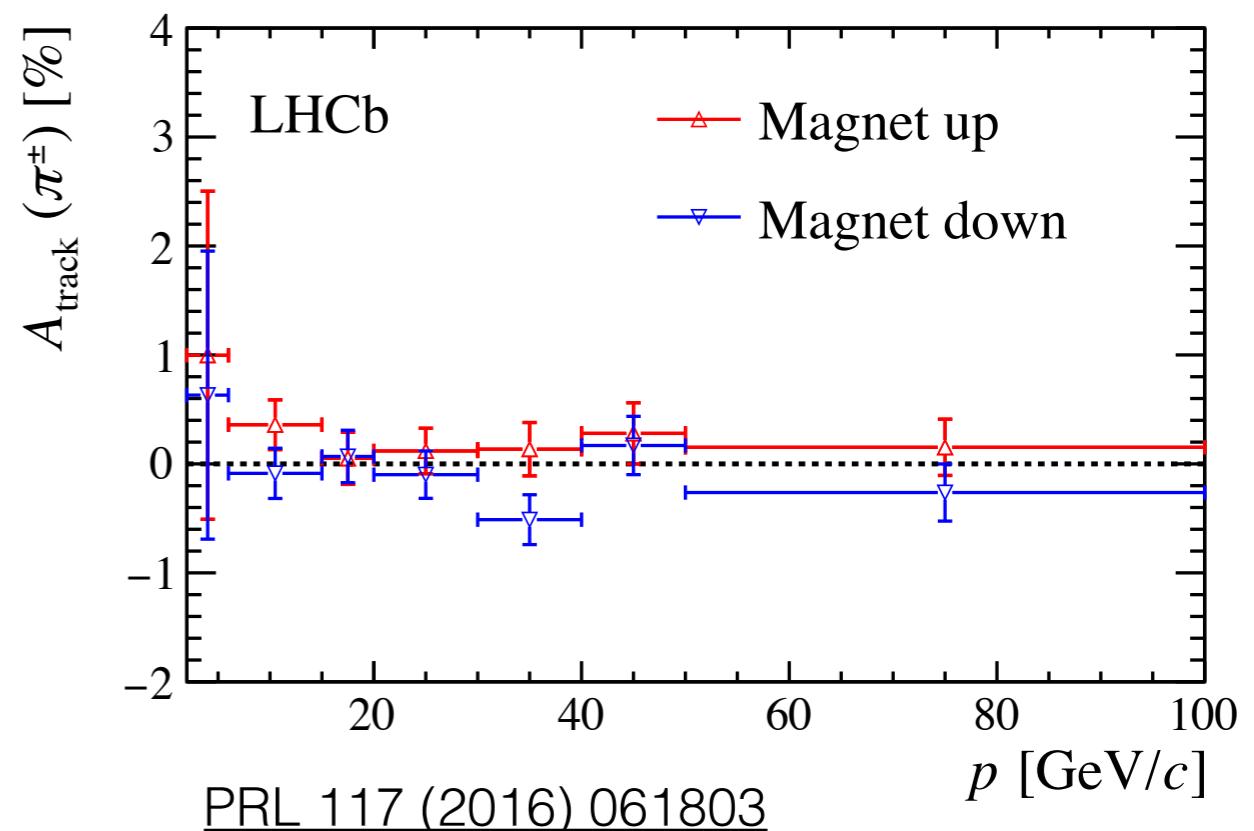


Detection asymmetry: tracking



- Two methods:
 - D^* partially reconstructed
 - $J/\Psi \rightarrow \mu\mu$ tag-and-probe

Combining both:

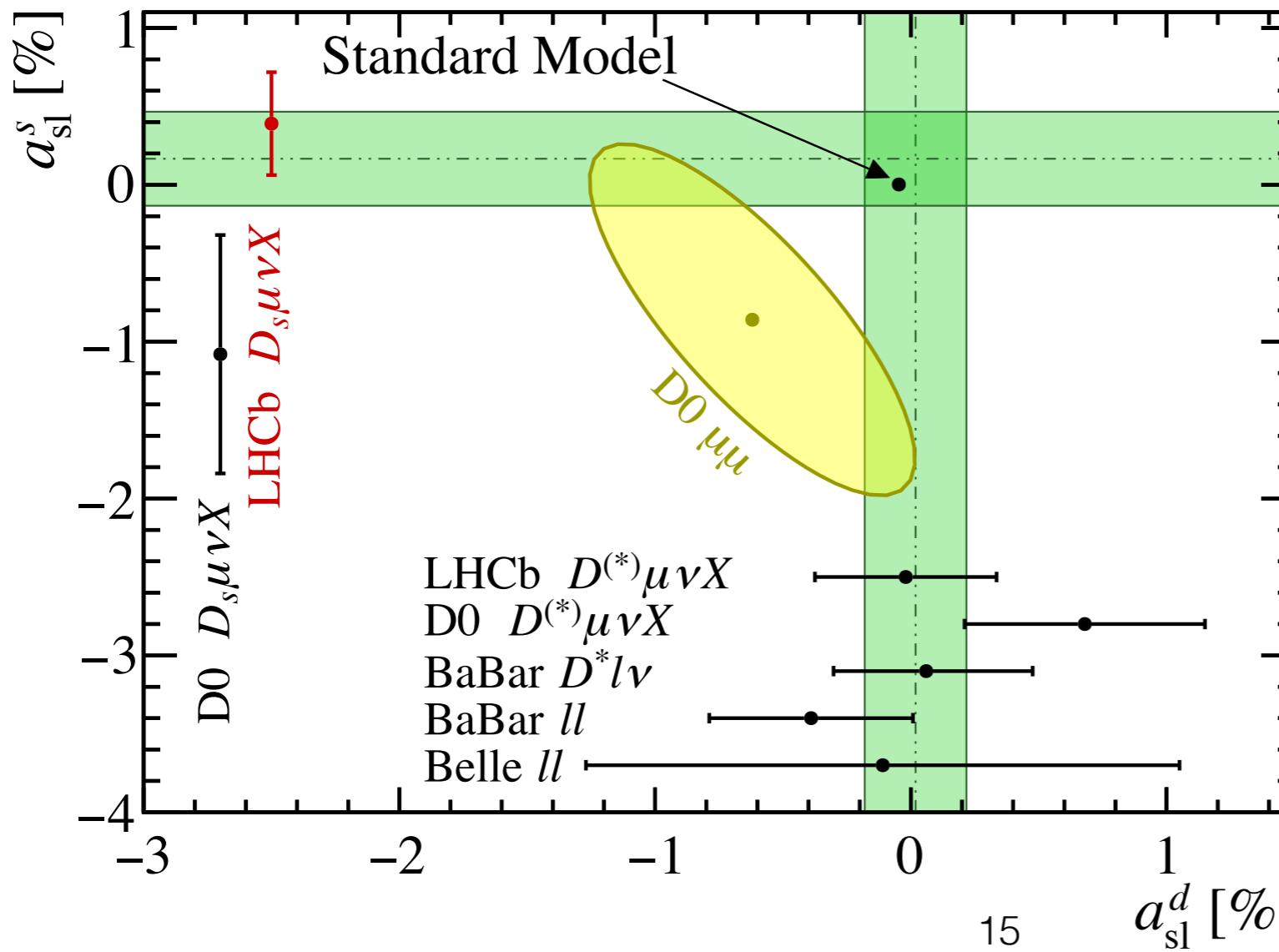


PRL 117 (2016) 061803

Results a_{sl}^s

using 3fb^{-1} :

$$a_{\text{sl}}^s = (0.39 \pm 0.26(\text{stat}) \pm 0.20(\text{syst}))\%$$



LHCb:

[PRL 117 \(2016\) 061803](#)

D0:

[PRD 105 \(2014\) 012002](#) (dimuon)

[PRL 110 \(2013\) 011801](#) (asls)

HFAG:

[arXiv:1412.7515](#) (asld)

Conclusion

- Measurement of lepton universality:

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

→ consistent with SM at 2.1σ

- Measured a_{sl}^s using the full run-I dataset (3fb^{-1}):

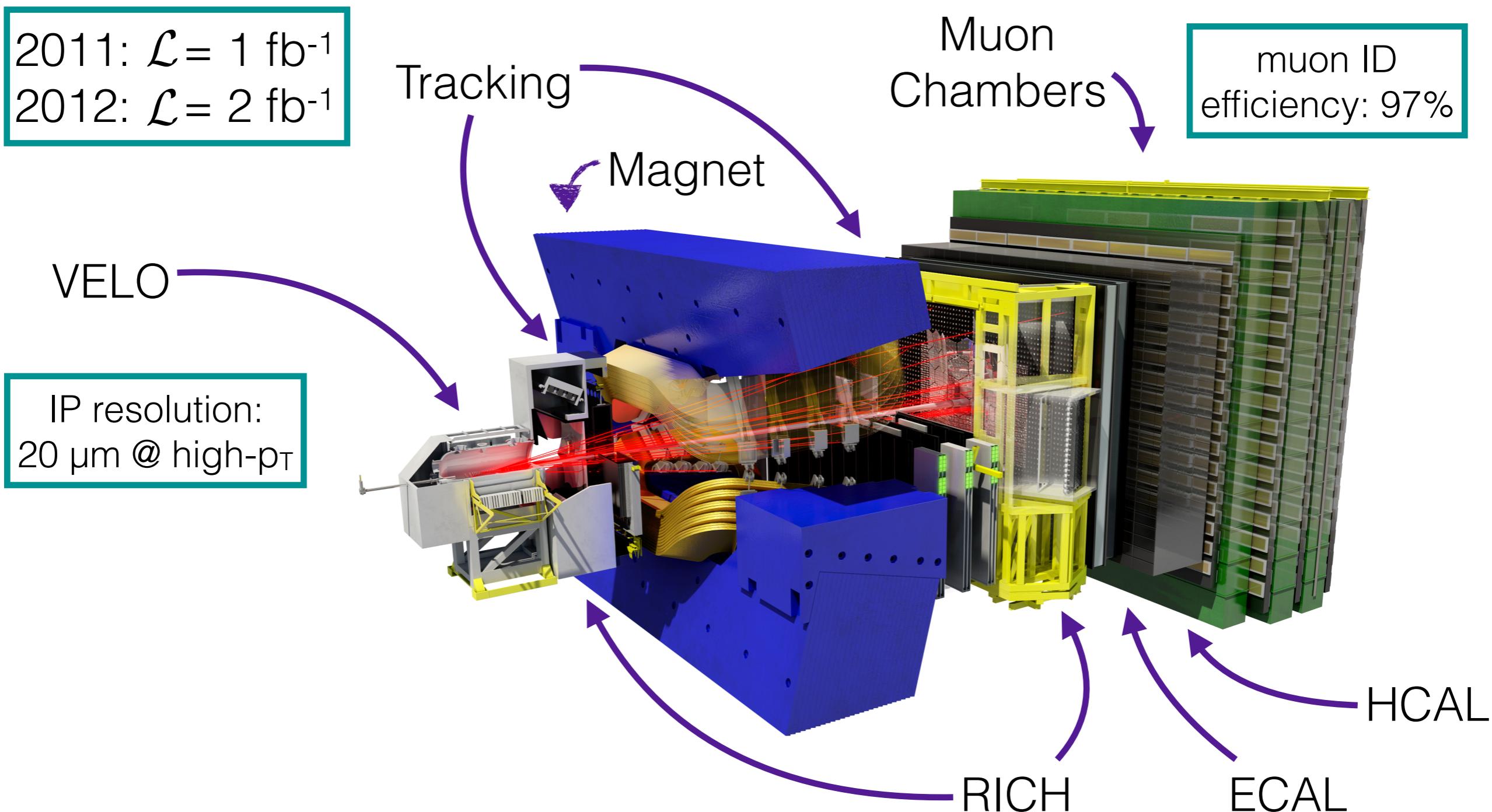
$$a_{\text{sl}}^s = (0.39 \pm 0.26(\text{stat}) \pm 0.20(\text{syst}))\%$$

→ most precise measurement of CP violation in the B_s system to date

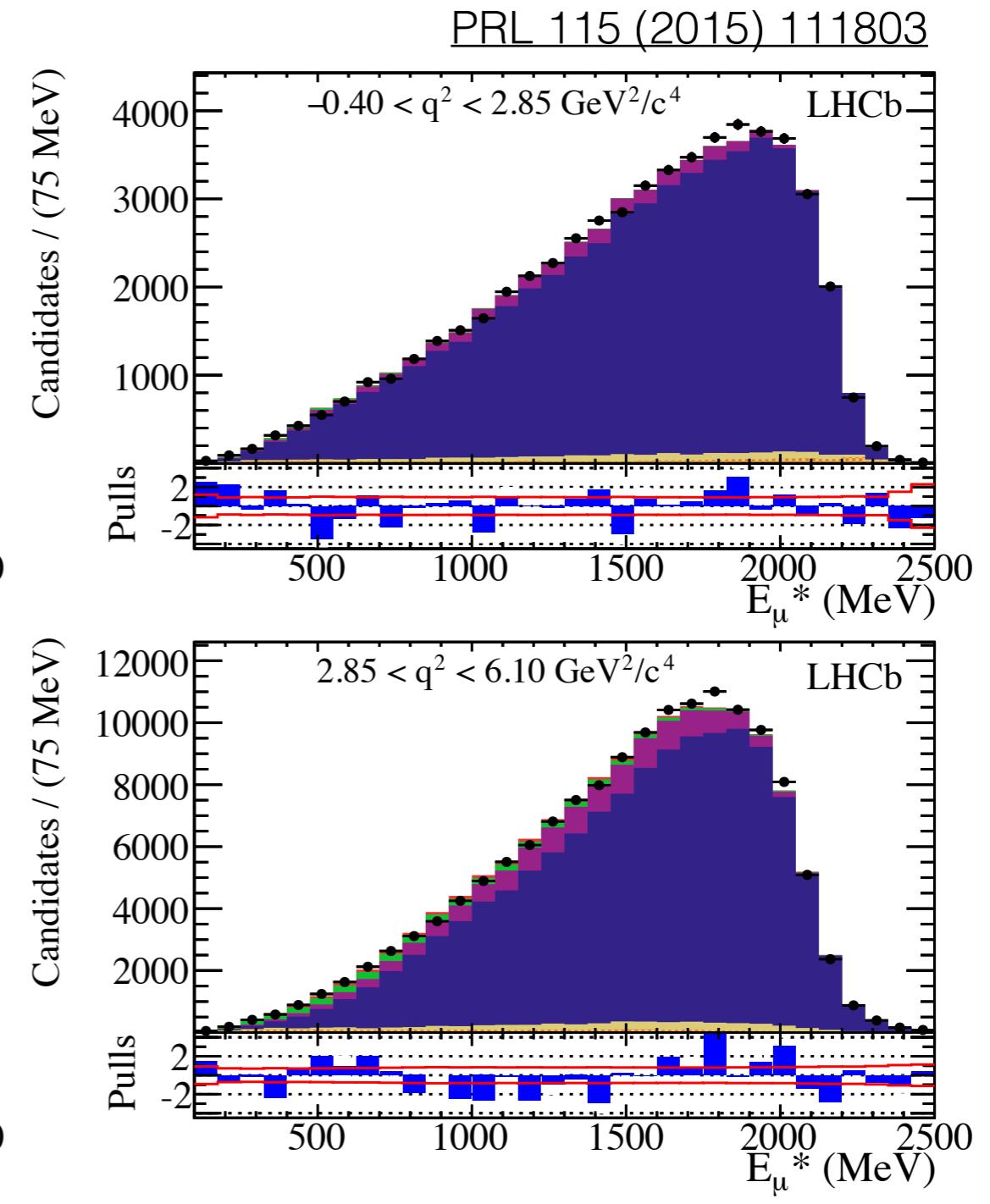
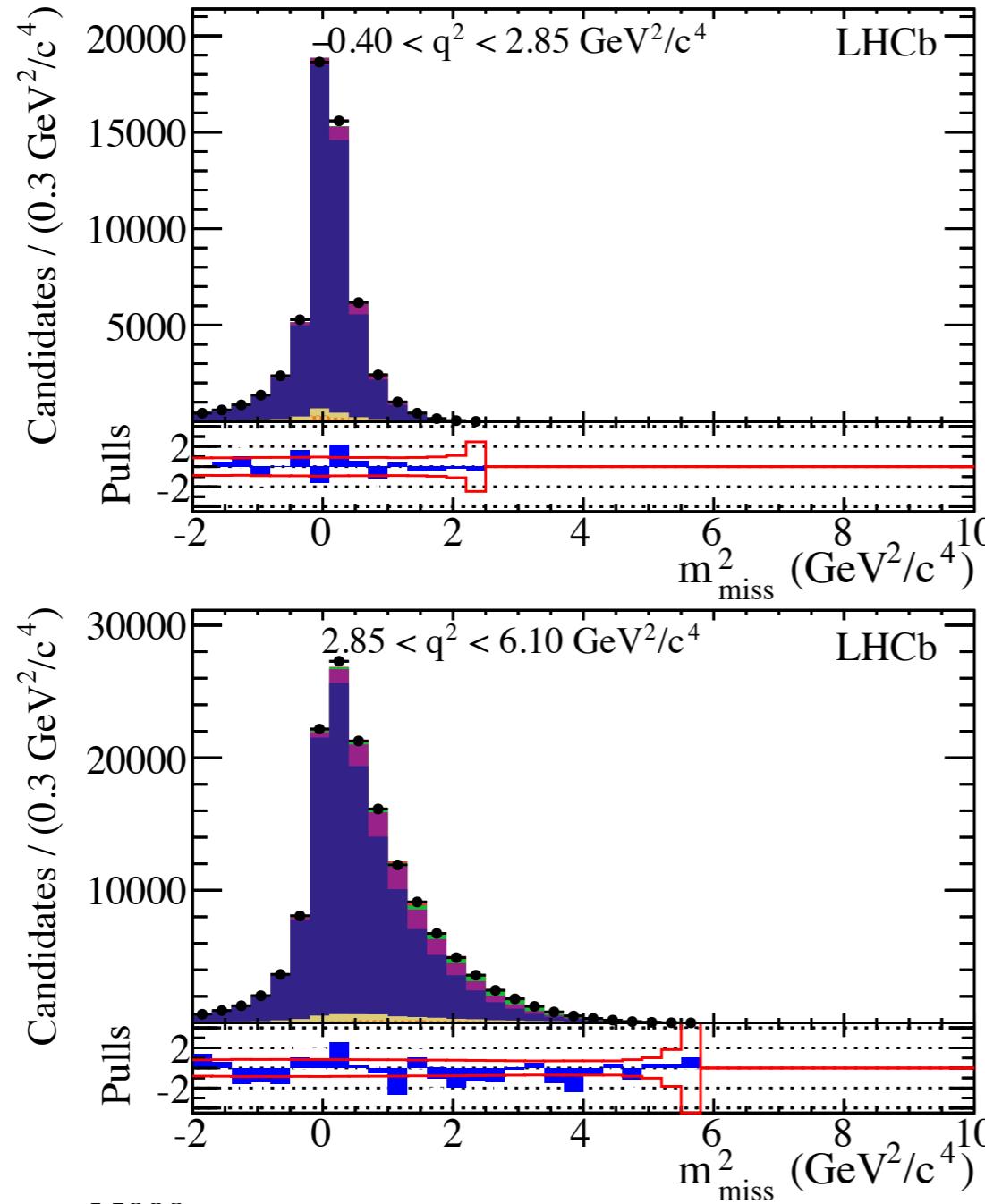
- Stay tuned for updates in run-II

Back-Up

The LHCb Detector



Fits for $R(D^*)$ in low q^2 bins



Systematic uncertainties in $\mathcal{R}(D^*)$

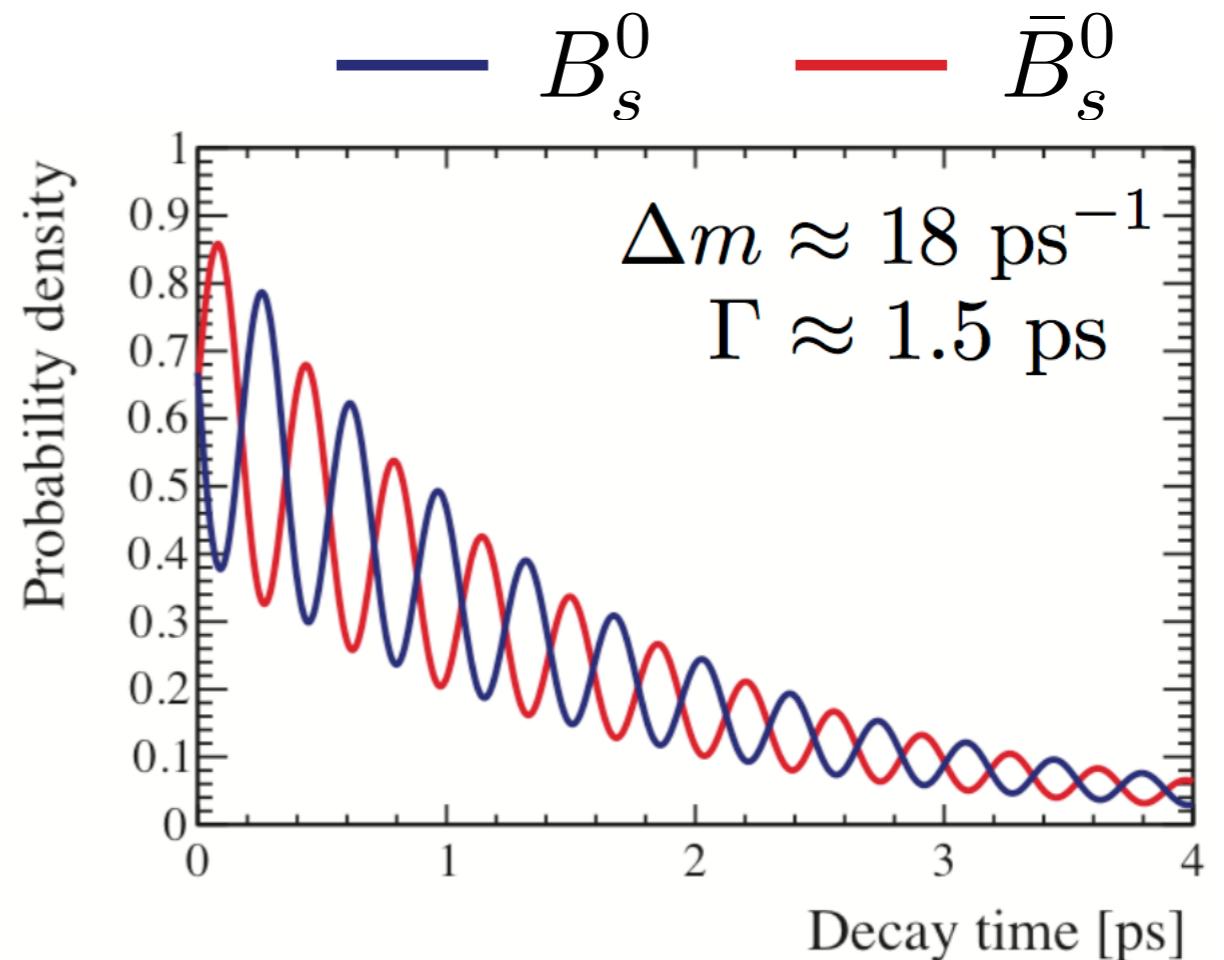
Table 1: Systematic uncertainties in the extraction of $\mathcal{R}(D^*)$.

Model uncertainties	Absolute size ($\times 10^{-2}$)
Simulated sample size	2.0
Misidentified μ template shape	1.6
$\bar{B}^0 \rightarrow D^{*+}(\tau^-/\mu^-)\bar{\nu}$ form factors	0.6
$\bar{B} \rightarrow D^{*+}H_c(\rightarrow \mu\nu X')X$ shape corrections	0.5
$\mathcal{B}(\bar{B} \rightarrow D^{**}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B} \rightarrow D^{**}\mu^-\bar{\nu}_\mu)$	0.5
$\bar{B} \rightarrow D^{**}(\rightarrow D^*\pi\pi)\mu\nu$ shape corrections	0.4
Corrections to simulation	0.4
Combinatorial background shape	0.3
$\bar{B} \rightarrow D^{**}(\rightarrow D^{*+}\pi)\mu^-\bar{\nu}_\mu$ form factors	0.3
$\bar{B} \rightarrow D^{*+}(D_s \rightarrow \tau\nu)X$ fraction	0.1
Total model uncertainty	2.8
Normalization uncertainties	Absolute size ($\times 10^{-2}$)
Simulated sample size	0.6
Hardware trigger efficiency	0.6
Particle identification efficiencies	0.3
Form-factors	0.2
$\mathcal{B}(\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau)$	< 0.1
Total normalization uncertainty	0.9
Total systematic uncertainty	3.0

Measuring a_{SL}^s in LHCb

We start with a different amount of B_s^0 and \bar{B}_s^0 mesons:

$$A_P = \frac{\sigma(pp \rightarrow B_s^0) - \sigma(pp \rightarrow \bar{B}_s^0)}{\sigma(pp \rightarrow B_s^0) + \sigma(pp \rightarrow \bar{B}_s^0)}$$



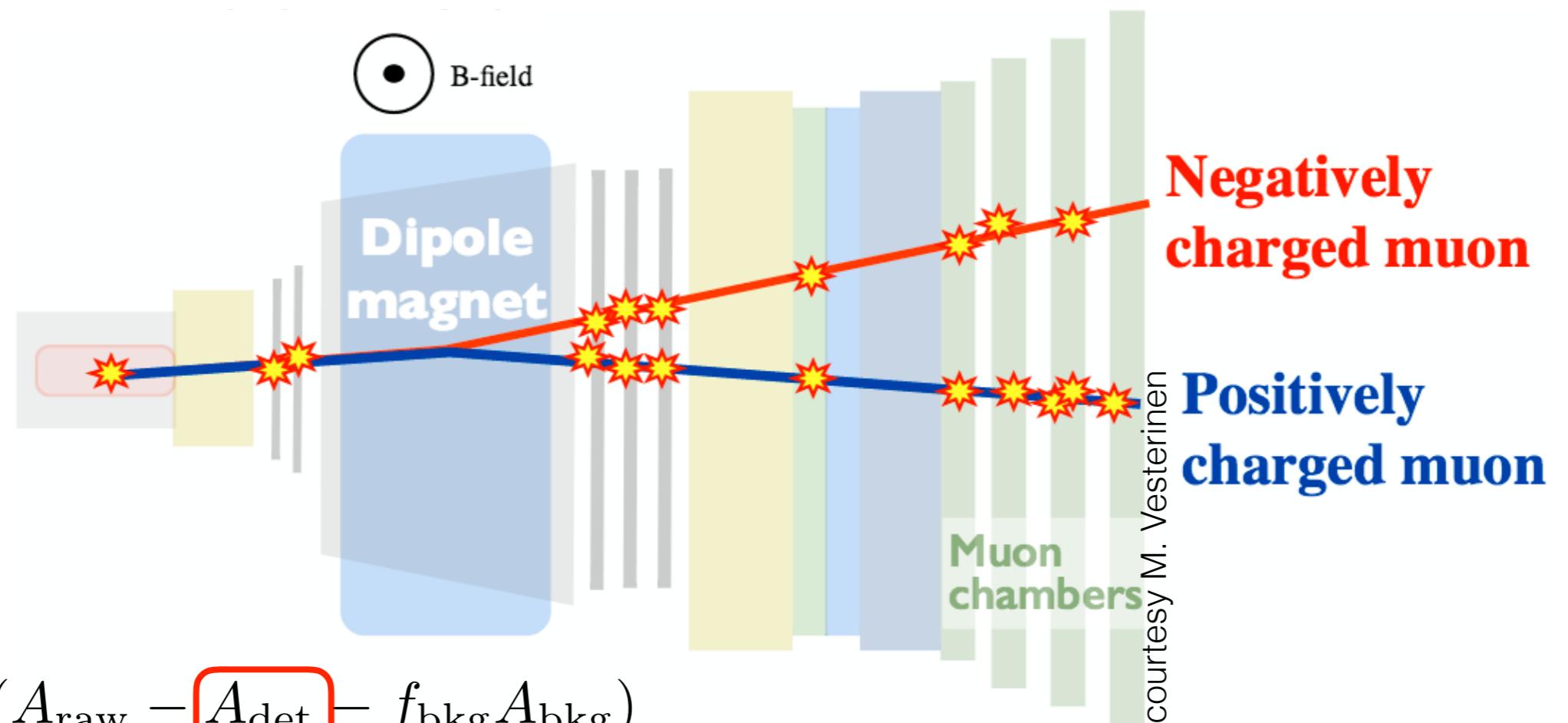
→ rapid oscillations dilute production asymmetry

Detection Asymmetries

$$A_{\text{det}} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})}$$

Due to:

- left-right asymmetric detector
- interaction asymmetries
- asymmetric pattern recognition

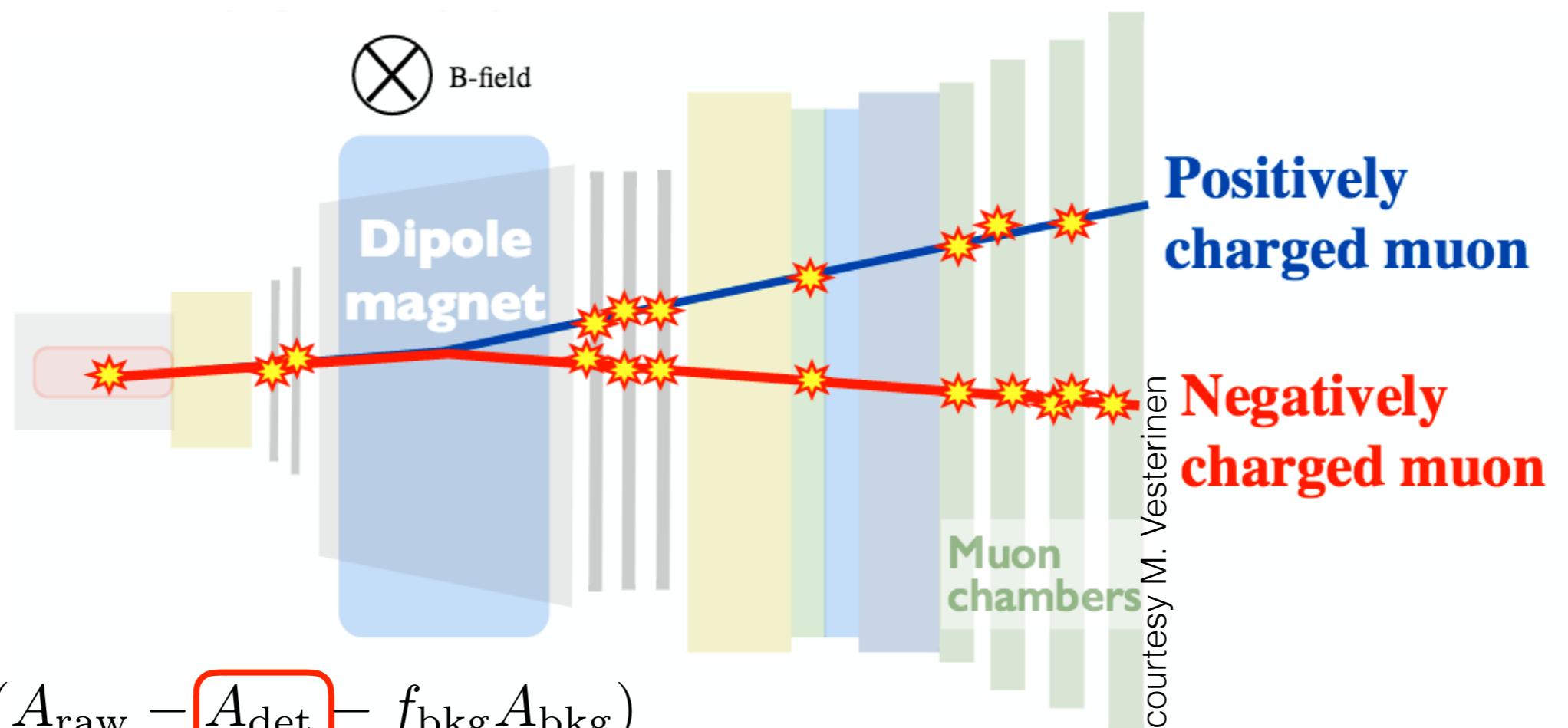


$$\frac{a_{\text{sl}}^s}{2} = \frac{1}{1 - f_{\text{bkg}}} (A_{\text{raw}} - \boxed{A_{\text{det}}} - f_{\text{bkg}} A_{\text{bkg}})$$

Detection Asymmetries

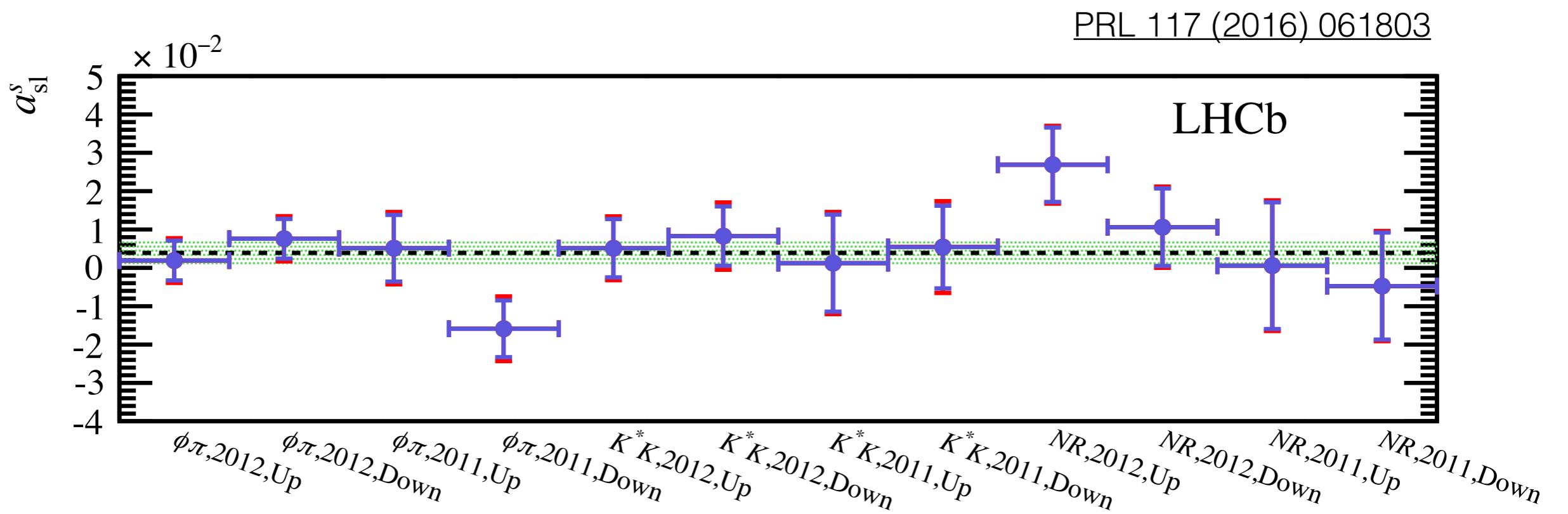
$$A_{\text{det}} = \frac{\varepsilon(f) - \varepsilon(\bar{f})}{\varepsilon(f) + \varepsilon(\bar{f})}$$

- largely measured by reversing magnet polarity
- measure the remaining asymmetry using data-driven methods



$$\frac{a_{\text{sl}}^s}{2} = \frac{1}{1 - f_{\text{bkg}}} (A_{\text{raw}} - \boxed{A_{\text{det}}} - f_{\text{bkg}} A_{\text{bkg}})$$

Results a_{sl}^s in bins



$$a_{\text{sl}}^s = (0.39 \pm 0.26(\text{stat}) \pm 0.20(\text{syst}))\%$$

Backgrounds in $a_{\text{S}1}^s$

Table 1: Branching fractions (\mathcal{B}), efficiency ratios ($\varepsilon_{\text{sig}}/\varepsilon_{\text{bkg}}$), background-over-signal ratio ($f_{\text{bkg}}/f_{\text{sig}}$) and effective asymmetries for the different background sources. The branching fractions are obtained from the PDG [1]. The signal branching fraction is $\mathcal{B} = (7.9 \pm 2.4)\%$. The b -hadron fractions from the pp collision are $f_u/f_s = f_d/f_s = (3.86 \pm 0.22)$ [2] and $f_{\Lambda_b^0}/f_s = (2.34 \pm 0.31)$ [3].

Mode	\mathcal{B} [%]	$\mathcal{B}(c \rightarrow \mu)$ [%]	$\varepsilon_{\text{sig}}/\varepsilon_{\text{bkg}}$	$f_{\text{bkg}}/f_{\text{sig}}$ [%]	A_{bkg} [%]
$B^+ \rightarrow D^{(*)0} D_s^{(*)+} X$	7.9 ± 1.4	6.5 ± 0.1	4.34	5.8 ± 1.1	-0.6 ± 0.6
$B^0 \rightarrow D^0 D_s^{(*)+} X$	5.7 ± 1.2	6.5 ± 0.1	4.08	4.4 ± 1.0	-0.18 ± 0.13
$B^0 \rightarrow D^- D_s^{(*)+} X$	4.6 ± 1.2	16.1 ± 0.3	6.41	5.6 ± 1.5	-0.18 ± 0.13
$B_s^0 \rightarrow D_s^{(*)-} D_s^{(*)+}$	4.5 ± 1.4	8.1 ± 0.4	3.68	1.0 ± 0.3	—
$\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^{(*)+} X$	$10.3_{-1.8}^{+2.1}$	4.5 ± 1.7	4.51	3.0 ± 1.4	$+0.5 \pm 0.8$
$B^- \rightarrow D_s^+ K^- \mu^- \nu X$	0.061 ± 0.010	—	2.43	1.3 ± 0.2	0.6 ± 0.6
$\bar{B}^0 \rightarrow D_s^+ K_s^0 \mu^- \nu X$	0.061 ± 0.010	—	2.89	1.1 ± 0.2	0.18 ± 0.13

Systematic uncertainties in a_{sl}^s

Table 1: Overview of contributions in the determination of a_{sl}^s , averaged over Dalitz plot regions, magnet polarities and data taking periods, with their statistical and systematic uncertainties. All numbers are in percent. The central value of a_{sl}^s is calculated according to Eq. 3. The uncertainties are added in quadrature and multiplied by $2/(1 - f_{\text{bkg}}) = 2.45$, which is the same for all twelve subsamples, to obtain the uncertainties on a_{sl}^s .

Source	Value	Stat. uncert.	Syst. uncert.
A_{raw}	0.11	0.09	0.02
$A_{\text{track}}(K^+K^-)$	-0.01	0.00	0.03
$A_{\text{track}}(\pi^-\mu^+)$	-0.01	0.05	0.04
A_{PID}	0.01	0.02	0.03
$A_{\text{trig}}(\text{hardware})$	-0.03	0.02	0.02
$A_{\text{trig}}(\text{software})$	0.00	0.01	0.02
$f_{\text{bkg}} A_{\text{bkg}}$	-0.02	—	0.03
f_{bkg}	—	—	0.06
Total a_{sl}^s	0.39	0.26	0.20