Measuring Semileptonic Asymmetries in LHCb

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MANCHESTER 1824
The University of Manchester

LHCb

Neutral Meson Mixing

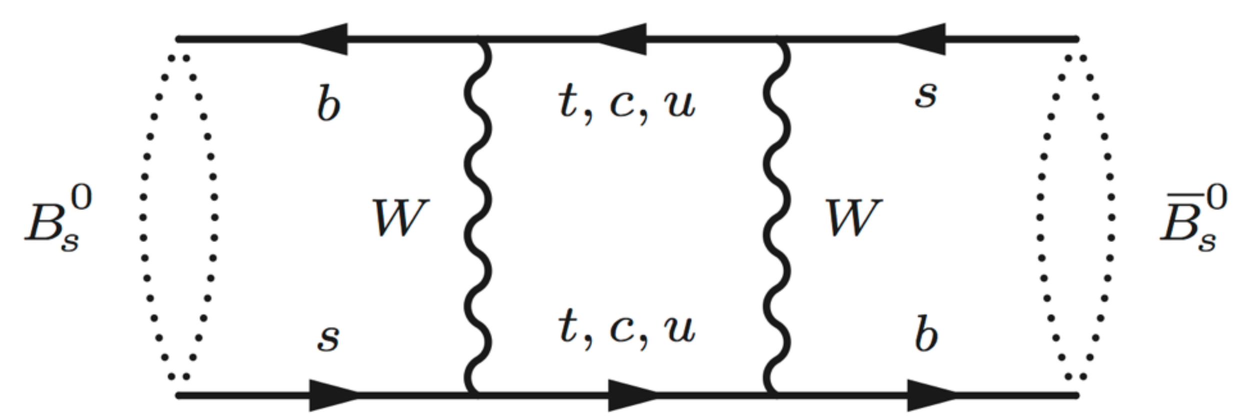
Neutral mesons oscillate into their own antiparticle:

$$i\frac{d}{dt}\begin{pmatrix}|B_q^0(t)\rangle\\|\bar{B}_q^0(t)\rangle\end{pmatrix}=(M-\frac{i}{2}\Gamma)\begin{pmatrix}|B_q^0(t)\rangle\\|\bar{B}_q^0(t)\rangle\end{pmatrix}$$

Heavy and light mass eigenstates:

$$|B_L^0\rangle = p|B_q^0\rangle + q|\bar{B}_q^0\rangle$$

$$|B_H^0\rangle = p|B_q^0\rangle - q|\bar{B}_q^0\rangle$$

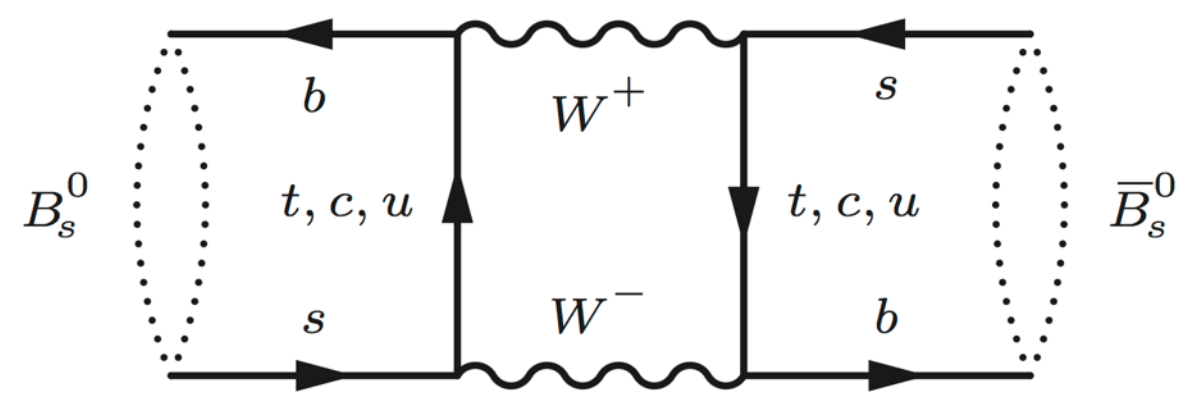


Different masses and decay widths:

$$\Delta m = m_H - m_L$$

$$\Delta\Gamma = \Gamma_L - \Gamma_H$$

mixing parameters



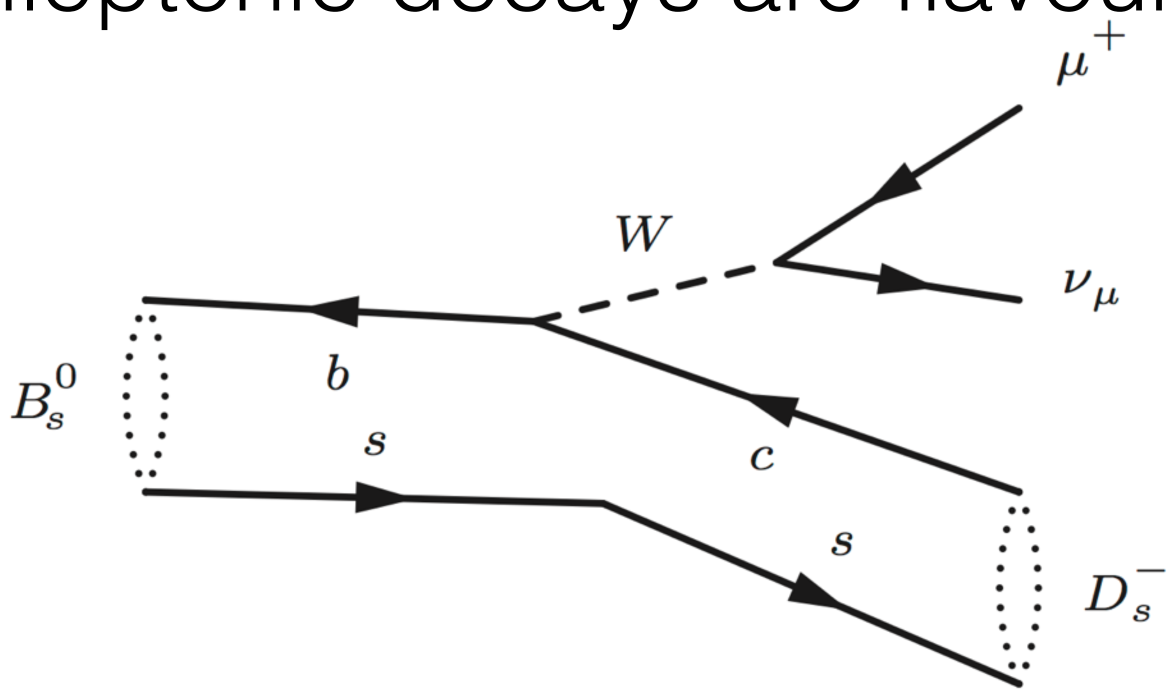
CP Violation in Mixing

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

Flavour specific asymmetry:

$$a_{\text{fs}} = \frac{\Gamma(\bar{B}_q \to B_q \to f) - \Gamma(B_q \to \bar{B}_q \to \bar{f})}{\Gamma(\bar{B}_q \to B_q \to f) + \Gamma(B_q \to \bar{B}_q \to \bar{f})} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

Semileptonic decays are flavour-specific:



CP violation if |q/p|≠1 → a_{fs} is very small in SM

How to measure $a_{\rm sl}$

$$a_{\rm sl} = \frac{\Gamma(\bar{B}_q \to B_q \to f) - \Gamma(B_q \to \bar{B}_q \to \bar{f})}{\Gamma(\bar{B}_q \to B_q \to f) + \Gamma(B_q \to \bar{B}_q \to \bar{f})}$$

2 methods:

- Inclusive like-sign dilepton asymmetry:

$$a_{\rm sl} = A_{ll} = \frac{\Gamma(l^+l^+) - \Gamma(l^-l^-)}{\Gamma(l^+l^+) + \Gamma(l^-l^-)}$$

time-integrated

- Untagged asymmetry:
  distinguish between B_s^0 and B_d^0:

$$\frac{N(B,t) - N(\bar{B},t)}{N(B,t) + N(\bar{B},t)} = \frac{a_{\rm sl}}{2}\left[1 - \frac{\cos \Delta m t}{\cosh \frac{1}{2}\Delta\Gamma t}\right]$$

time-dependent

Experimental Overview before LHCb

SM predictions:

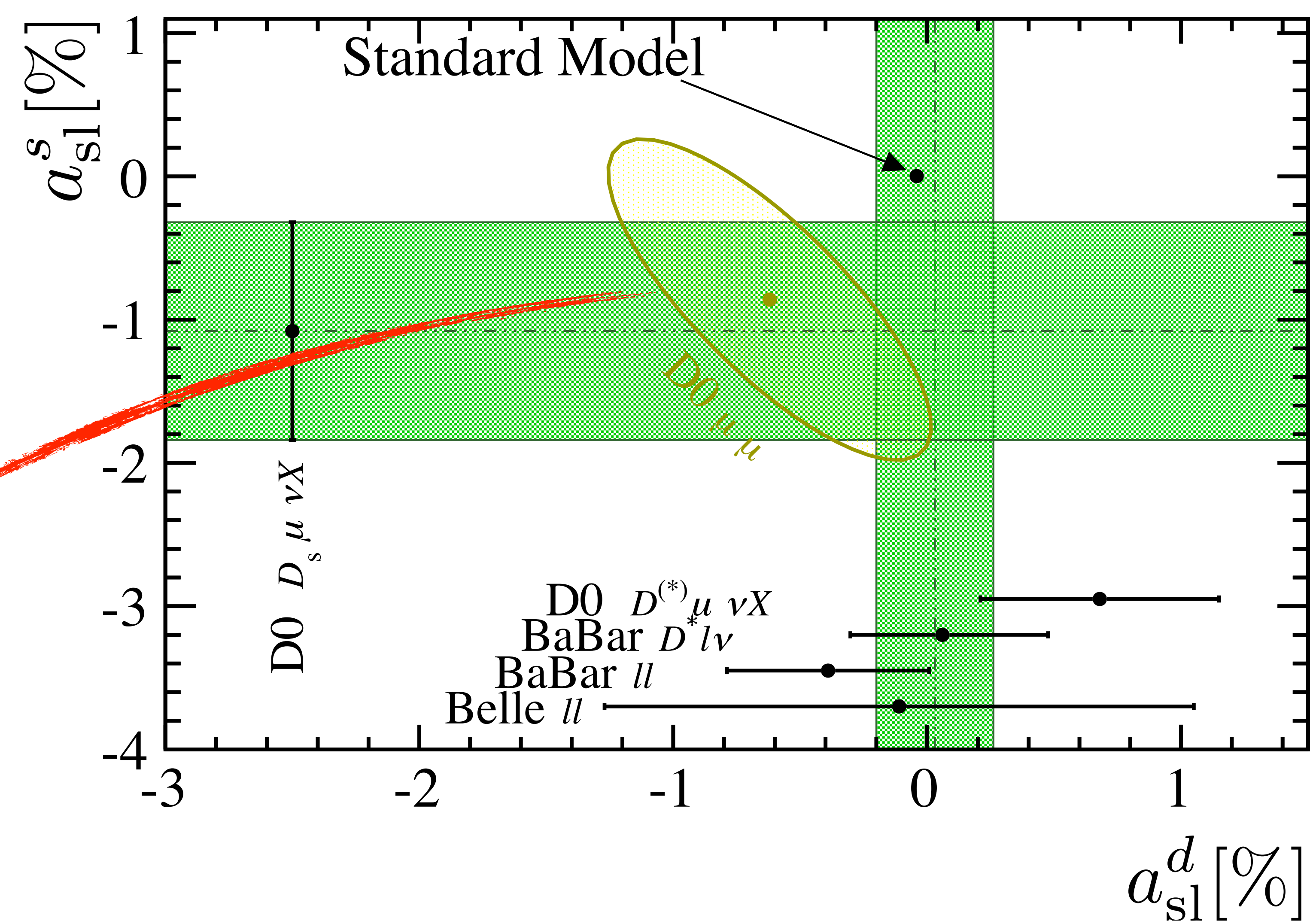
$$a_{\rm sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$$

$$a_{\rm sl}^s = (1.9 \pm 0.3) \times 10^{-5}$$

A.Lenz, 1205.1444 [hep-ph]

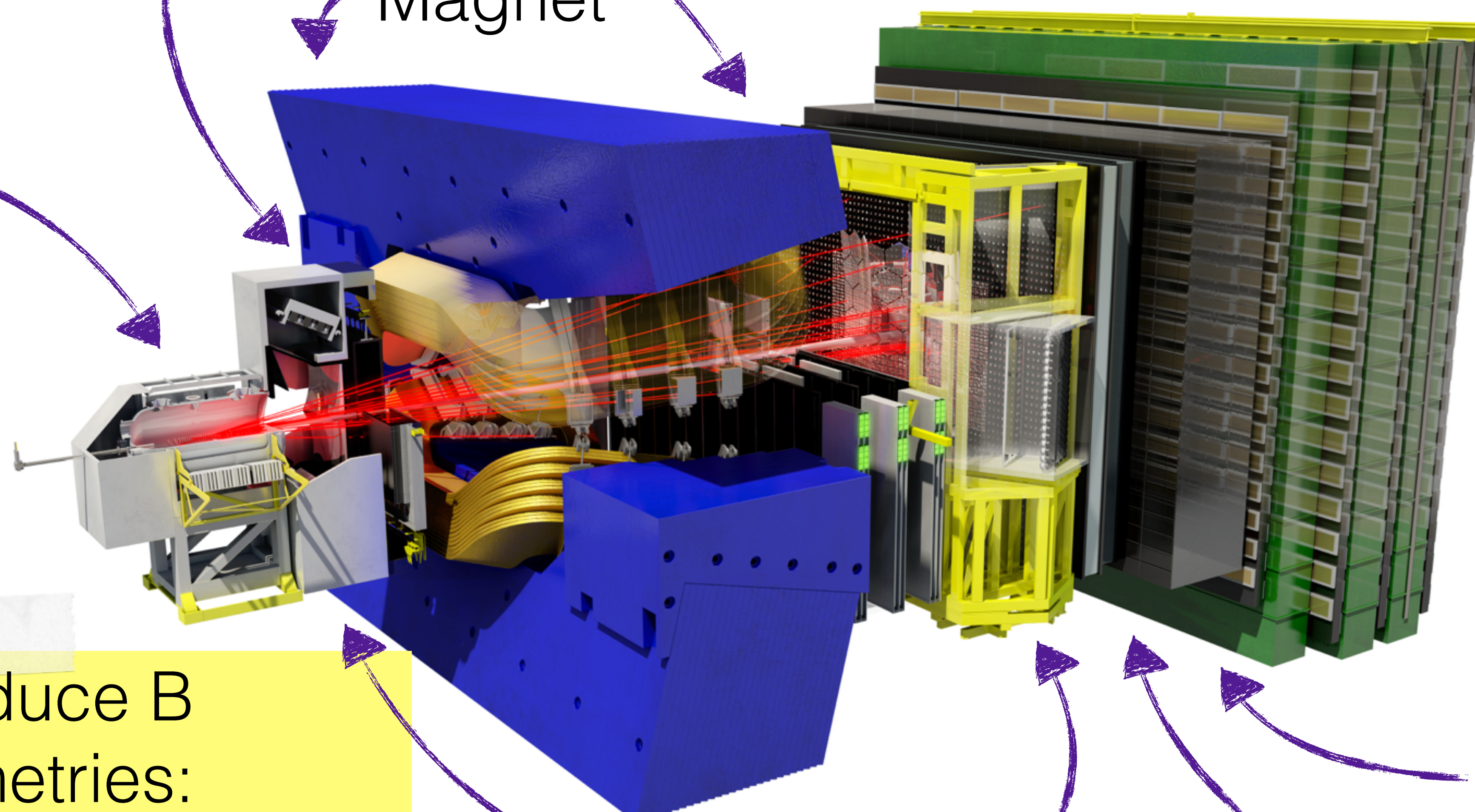
D0 measurement is 3σ away from SM

Phys. Rev. D 89, 012002



The LHCb Detector

2011: $\mathcal{L}$ = 1 fb^{-1}
2012: $\mathcal{L}$ = 2 fb^{-1}



muon ID efficiency: 97%

IP resolution: 20 μm @ high-p_T

pp collisions introduce B production asymmetries:

$$A_P = \frac{\sigma(pp \to \bar{B}) - \sigma(pp \to B)}{\sigma(pp \to \bar{B}) + \sigma(pp \to B)}$$ ~1%

Measuring a_{sl} in LHCb

$$\frac{N(B,t)-N(\bar{B},t)}{N(B,t)+N(\bar{B},t)}=\frac{a_{\mathrm{sl}}}{2}\left[1-\frac{\cos\Delta m t}{\cosh\frac{1}{2}\Delta\Gamma t}\right]$$

Measuring a_{sl} in LHCb

$$\frac{N(B,t)-N(\bar{B},t)}{N(B,t)+N(\bar{B},t)} = \frac{a_{\mathrm{sl}}}{2}\left[1-\frac{\cos\Delta m t}{\cosh\frac{1}{2}\Delta\Gamma t}\right]$$

For a_{sl}^{d}, including detection and production asymmetries:

$$A_{\mathrm{meas}}(t) = \frac{N(B,t)-N(\bar{B},t)}{N(B,t)+N(\bar{B},t)} = \frac{a_{\mathrm{sl}}^{d}}{2} + A_D - \left(\frac{a_{\mathrm{sl}}^{d}}{2}+A_P\right)\frac{\cos\Delta m_d t}{\cosh\frac{1}{2}\Delta\Gamma_d t}$$

Measuring $a_{\rm sl}$ in LHCb

$$\frac{N(B,t)-N(\bar{B},t)}{N(B,t)+N(\bar{B},t)} = \frac{a_{\rm sl}}{2}\left[1-\frac{\cos\Delta m t}{\cosh\frac{1}{2}\Delta\Gamma t}\right]$$

For $a^d_{\rm sl}$, including detection and production asymmetries:

$$A_{\rm meas}(t) = \frac{N(B,t)-N(\bar{B},t)}{N(B,t)+N(\bar{B},t)} = \frac{a^d_{\rm sl}}{2} + A_D - \left(\frac{a^d_{\rm sl}}{2} + A_P\right)\frac{\cos\Delta m_d t}{\cosh\frac{1}{2}\Delta\Gamma_d t}$$

For $a^s_{\rm sl}$,the measurement can be made time-integrated:

$$A_{\rm meas} = \frac{N(\mu^+D_s^-)-N(\mu^-D_s^+)}{N(\mu^+D_s^-)+N(\mu^-D_s^+)} = \frac{a^s_{\rm sl}}{2} + A_D - \left(\frac{a^s_{\rm sl}}{2} + A_P\right)\frac{\int_0^\infty e^{-\Gamma_s t}\cos(\Delta m_s t)\varepsilon(t)\,dt}{\int_0^\infty e^{-\Gamma_s t}\cosh(\frac{1}{2}\Delta\Gamma_s t)\varepsilon(t)\,dt}$$

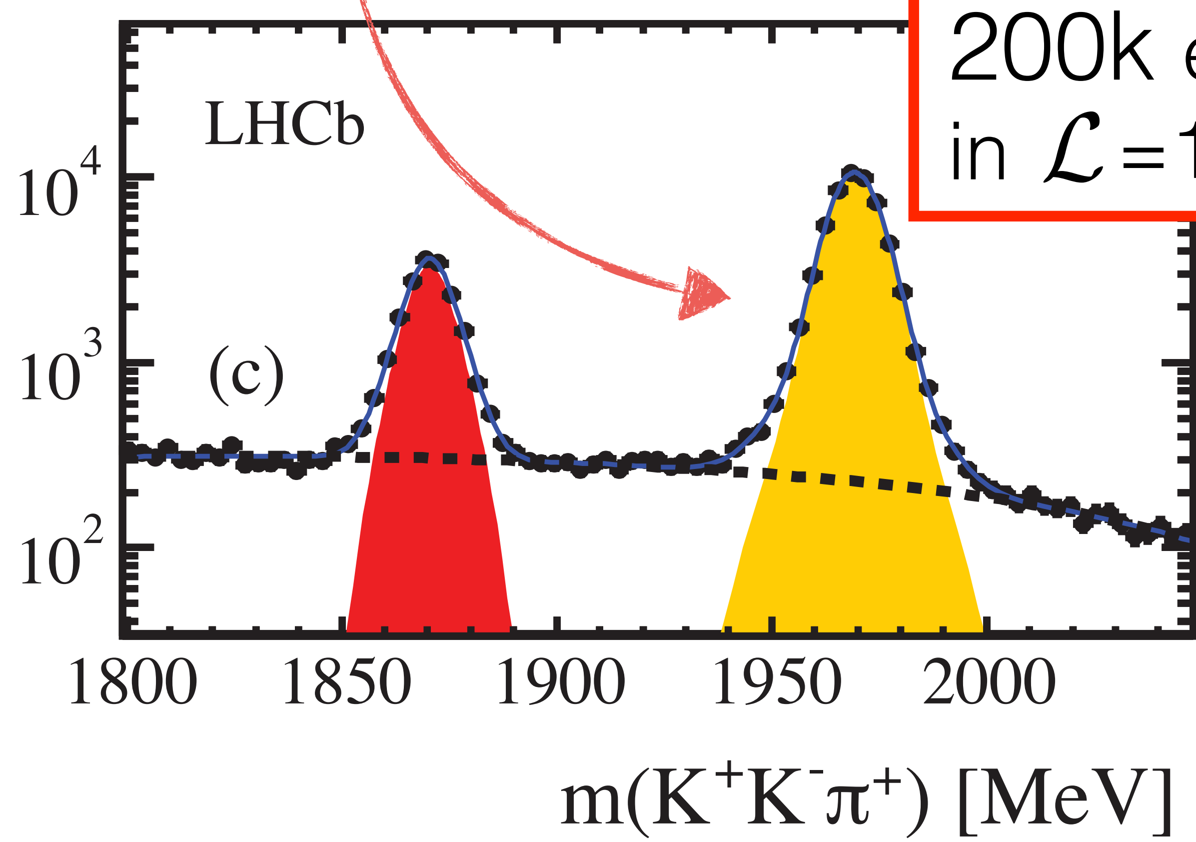
a_{sl}^s in LHCb

$$A_{\rm meas} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^-) + N(\mu^- D_s^+)} = \frac{a_{\rm sl}^s}{2} + A_D - \left(\frac{a_{\rm sl}^s}{2} + A_P\right) \frac{\int_0^\infty e^{-\Gamma_s t}\cos(\Delta m_s t)\varepsilon(t)\,dt}{\int_0^\infty e^{-\Gamma_s t}\cosh(\frac{1}{2}\Delta\Gamma_s t)\varepsilon(t)\,dt}$$

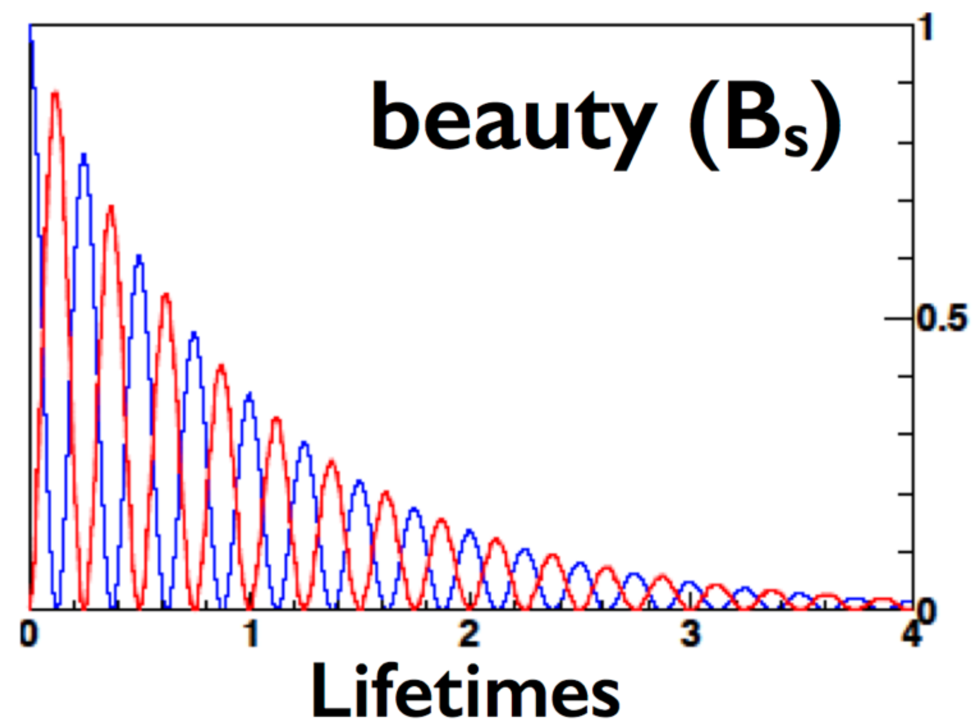
$<10^{-4}$ due to fast B_s oscillations

$B_s \to D_s (\to K K \pi) \mu \nu_\mu$

only via φ resonance

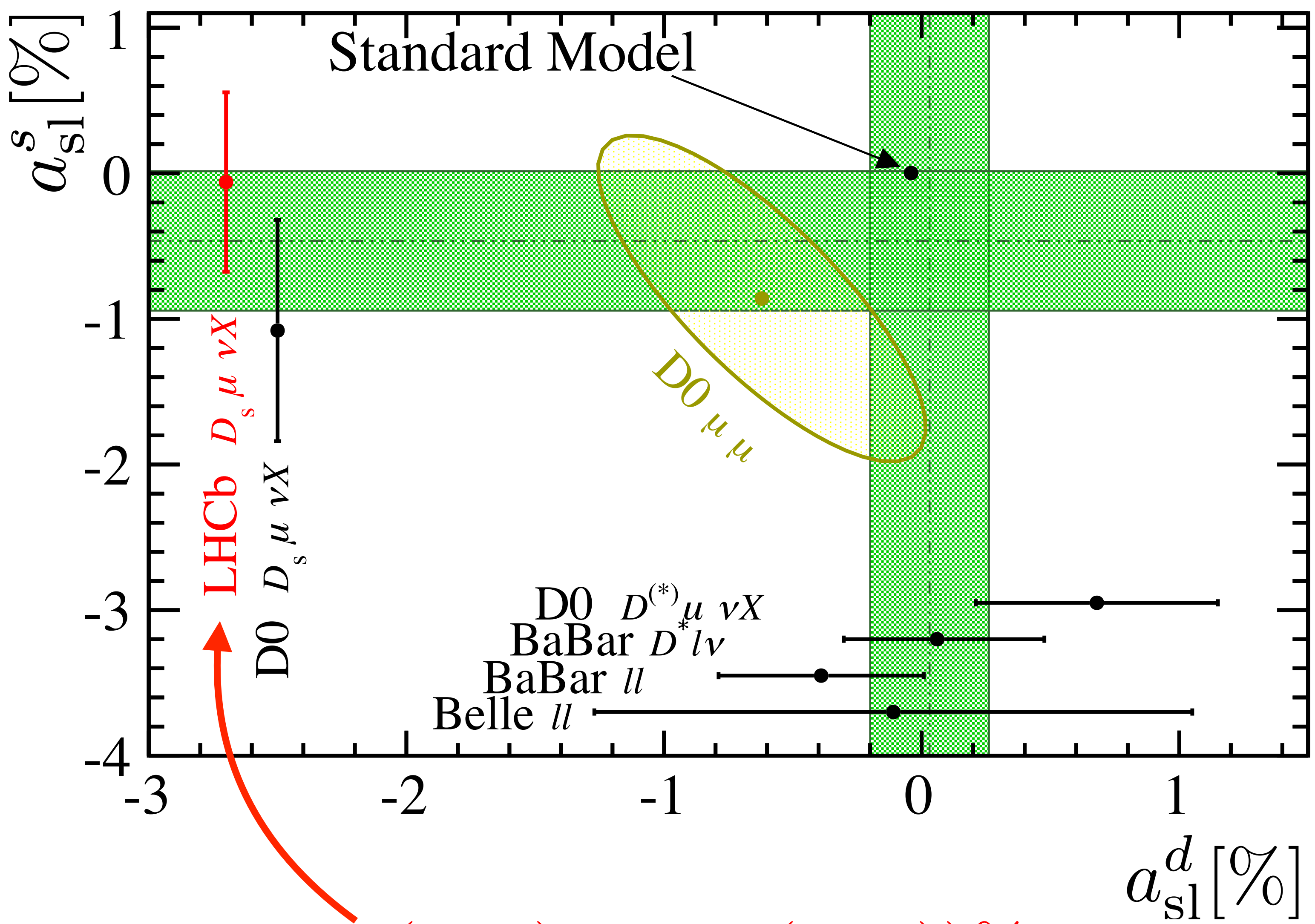


200k events in $\mathcal{L}$=1 fb^{-1}



Phys. Lett. B 728 607-615 (2014)

Experimental Overview including LHCb a_{sl}^{s} Result



$$a_{\mathrm{sl}}^{s} = (-0.06 \pm 0.50(\mathrm{stat}) \pm 0.36(\mathrm{syst}))\%$$

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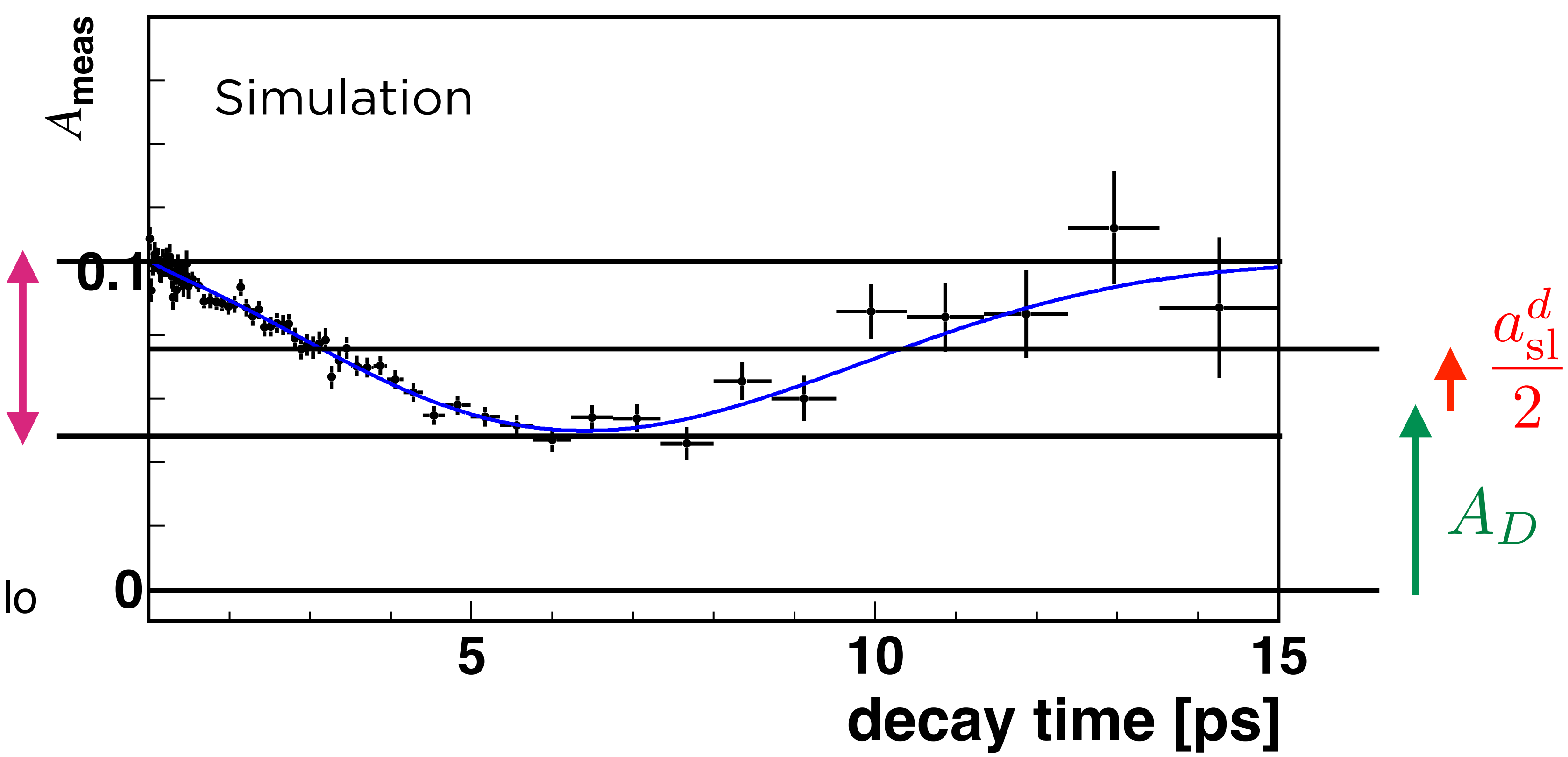
Measuring $a_{\rm sl}^d$ in LHCb

$$A_{\rm meas}(t) = \frac{N(B,t) - N(\bar{B},t)}{N(B,t) + N(\bar{B},t)} = \frac{a_{\rm sl}^d}{2} + A_D - \left(\frac{a_{\rm sl}^d}{2} + A_P\right)\frac{\cos \Delta m_d t}{\cosh \frac{1}{2}\Delta\Gamma_d t}$$

Time-dependent fit to disentangle A_P and $a_{\rm sl}^d$:

$$\left|-2\left(\frac{a_{\rm sl}^d}{2} + A_P\right)\right|$$

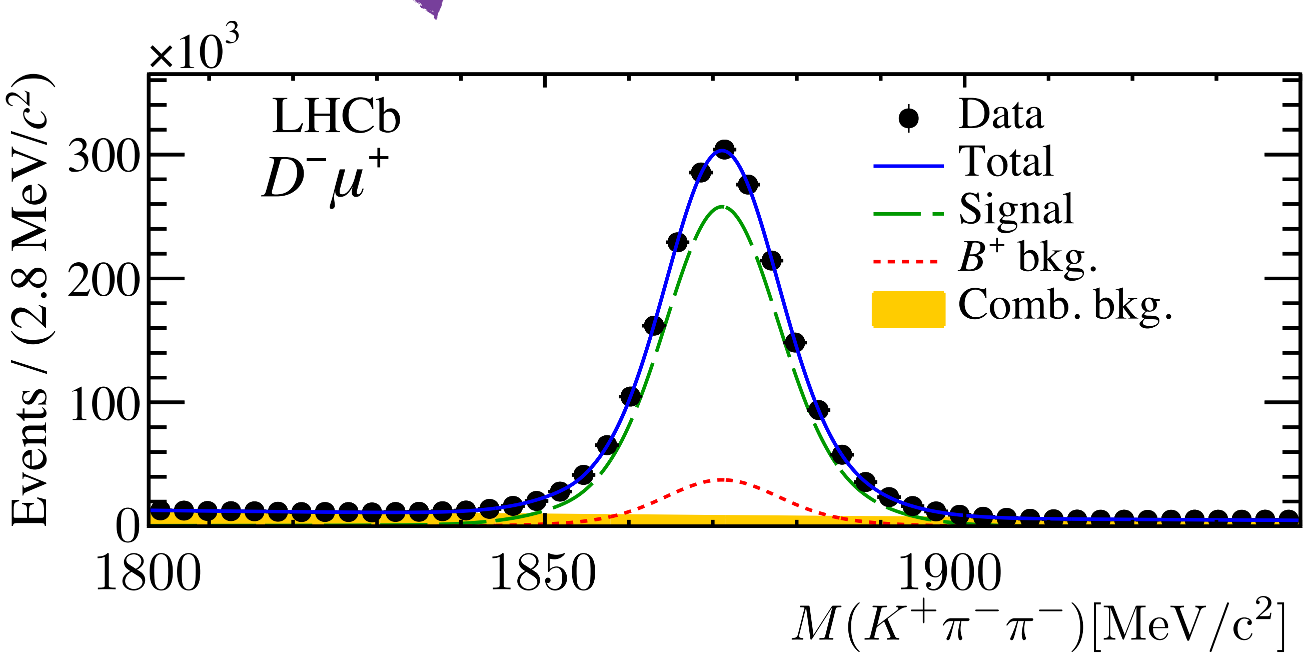


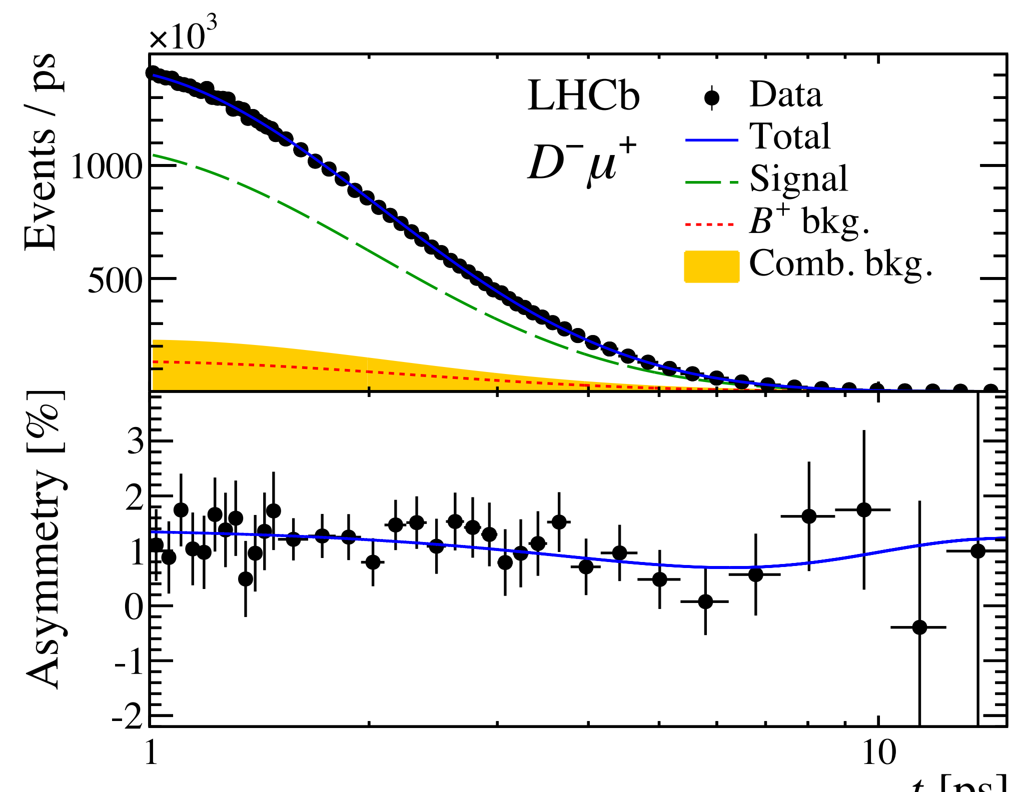
Courtesy of Lucia Grillo

Measuring a_{sl}^{d} in LHCb

2 decay modes:

- $B_d \to D^{*+} \mu \nu_\mu X$ — 0.3M events in $\mathcal{L}$ =3 fb^{-1}
- $B_d \to D^{+} \mu \nu_\mu X$ — 1.8M events in $\mathcal{L}$ =3 fb^{-1}





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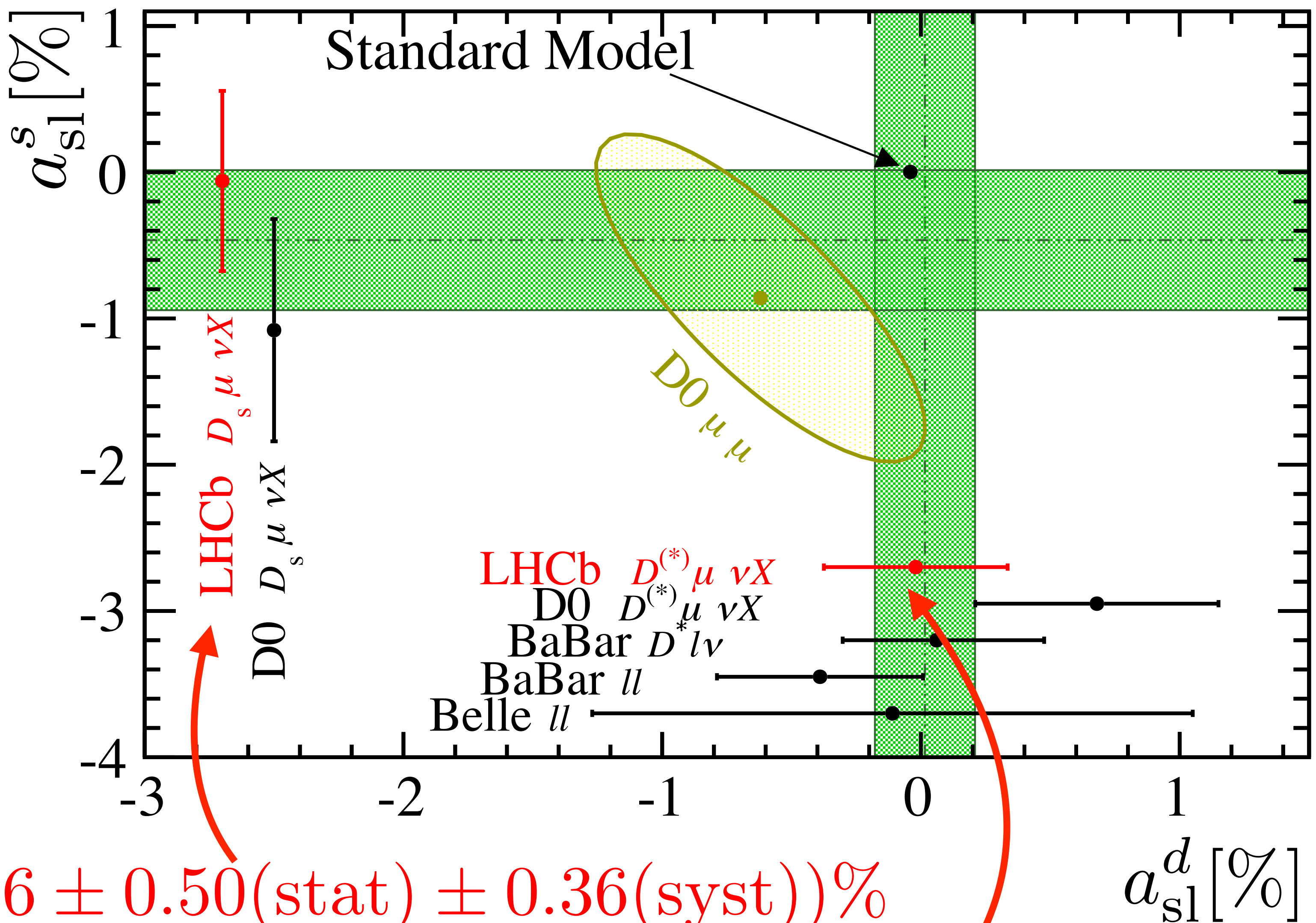
Experimental Overview including LHCb $a_{\rm sl}^{d}$ Results



$$a_{\rm sl}^{s} = (-0.06 \pm 0.50({\rm stat}) \pm 0.36({\rm syst}))\%$$

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$$a_{\rm sl}^{d} = (-0.02 \pm 0.19({\rm stat}) \pm 0.30({\rm syst}))\%$$

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Systematic Uncertainties

For the $a_{\rm sl}^s$ analysis:

Source of uncertainty	σ(A_{meas})[%]
Tracking asymmetries	**0.26**
Muon asymmetries	**0.16**
Fitting	0.15
Backgrounds	0.10
Total	0.36

$$a_{\rm sl}^s = (-0.06 \pm 0.50({\rm stat}) \pm 0.36({\rm syst}))\%$$

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For the $a_{\rm sl}^d$ analysis:

Source of uncertainty	σ(A_{meas})[%]
Detection asymmetry	**0.26**
B plus	0.13
Baryonic backgrounds	0.07
Decay time model	0.05
Other background	0.04
Total	0.30

$$a_{\rm sl}^d = (-0.02 \pm 0.19({\rm stat}) \pm 0.30({\rm syst}))\%$$

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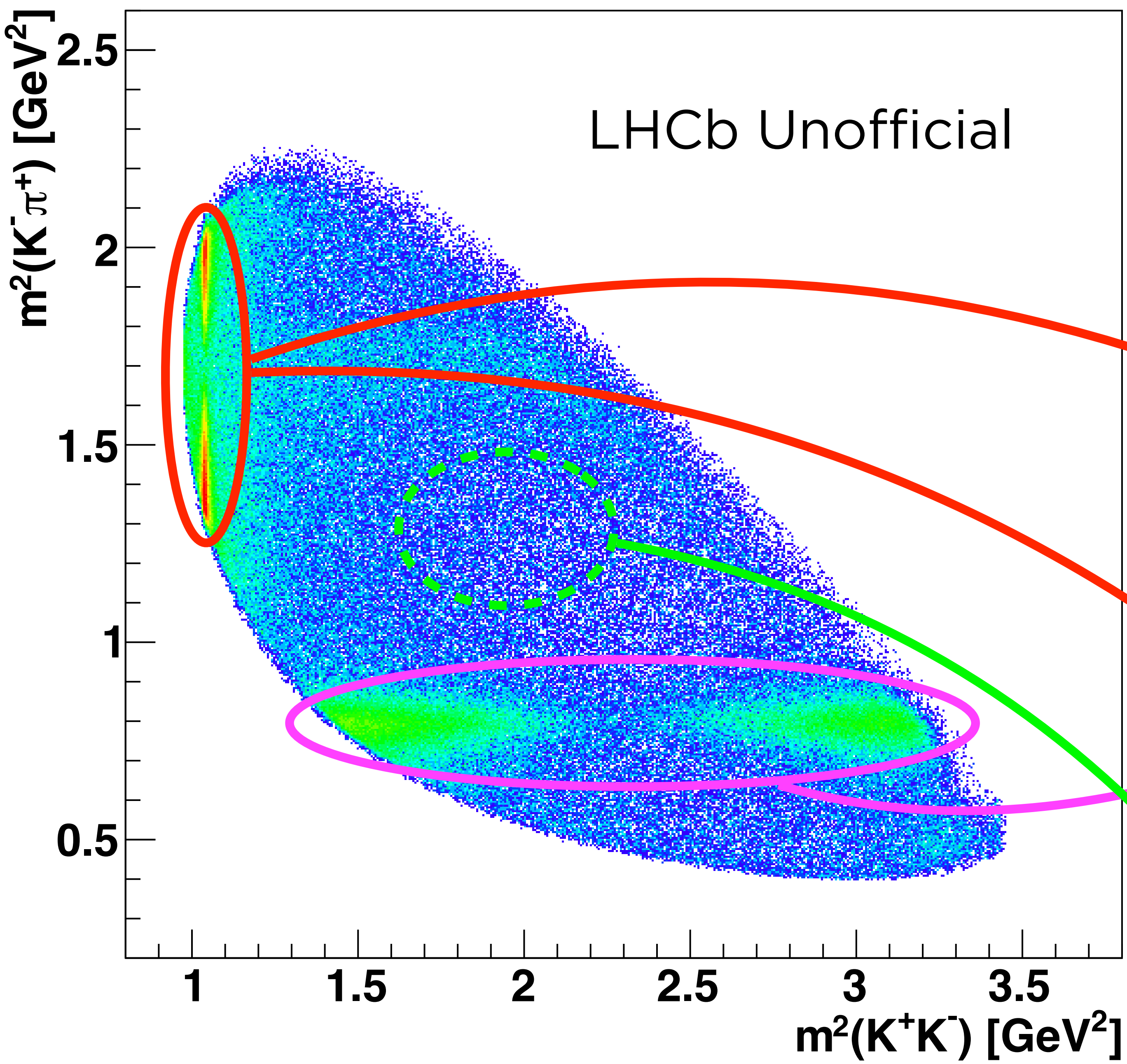
Dominated by control mode statistics

Improvements for the 2012 a_{sl}^{s} analysis

Expanding the Dalitz Plane



$B_s \rightarrow D_s \mu \nu_\mu$

Using 2011 data:

- $D_s \rightarrow \phi (\rightarrow K K) \pi$

Using 2012 data:

- $D_s \rightarrow \phi (\rightarrow K K) \pi$
- $D_s \rightarrow K^* (\rightarrow K \pi) K$
- Remaining phase space

Reducing Systematic Uncertainties

From the 2011 analysis:

Source of uncertainty	$\sigma(A_{meas})$[%]
Tracking asymmetries	**0.26**
Muon asymmetries	0.16
Fitting	0.15
Backgrounds	0.10
Total	0.36

$$a_{\mathrm{sl}}^{s} = (-0.06 \pm 0.50(\mathrm{stat}) \pm 0.36(\mathrm{syst}))\%$$

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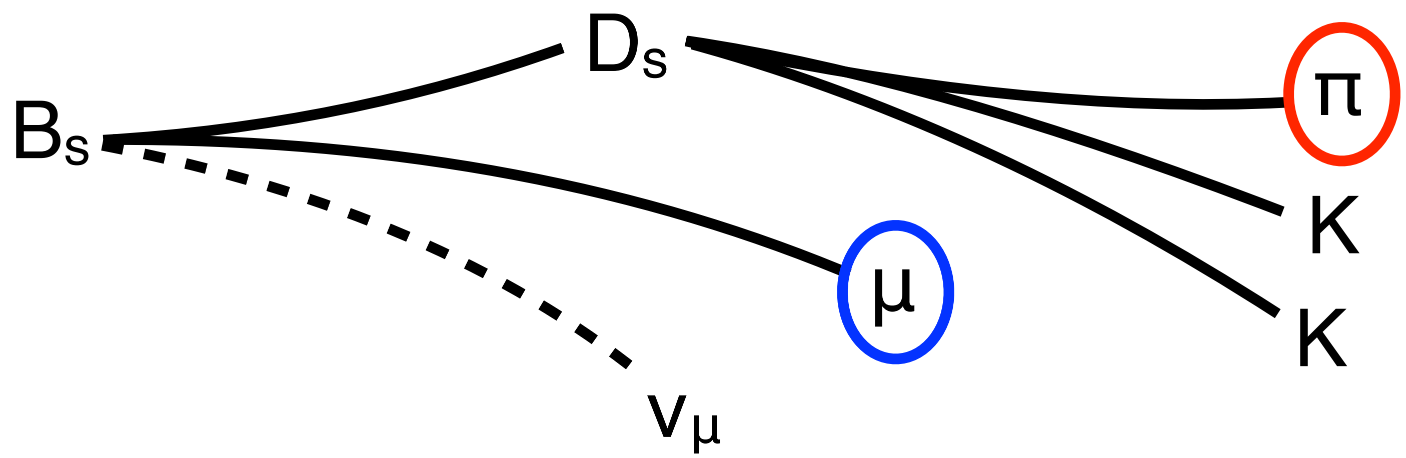
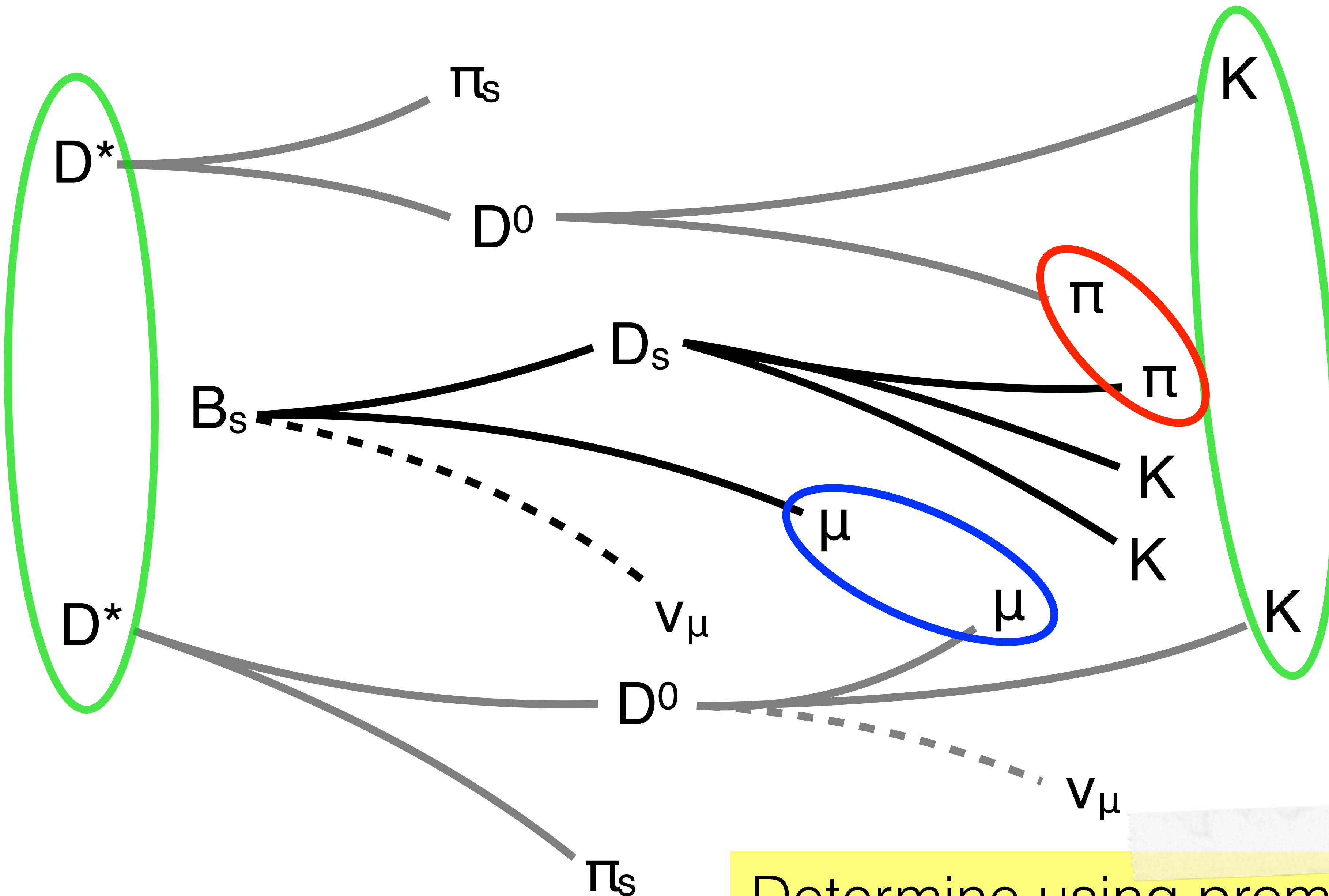
μπ Detection Asymmetries



$\mu\pi$ Detection Asymmetries



Determine using prompt charm decays:

- **D*** $\rightarrow D^0 (\rightarrow$ **K** **π**$) \pi_s$
- **D*** $\rightarrow D^0 (\rightarrow$ **K** **μ** $\nu_\mu) \pi_s$

μπ Detection Asymmetries

Efficiency ratios:

$$\frac{\varepsilon(\mu^+\pi^-)}{\varepsilon(\mu^-\pi^+)} = \frac{N(D^0 \to K^-\mu^+\nu_\mu)}{N(\overline{D}^0 \to K^+\mu^-\overline{\nu}_\mu)} \times \frac{N(\overline{D}^0 \to K^+\pi^-)}{N(D^0 \to K^-\pi^+)}$$

μπ Detection Asymmetries

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μπ asymmetries:

$$A_{\mu\pi} = \frac{\varepsilon(\mu^+\pi^-)/\varepsilon(\mu^-\pi^+) - 1}{\varepsilon(\mu^+\pi^-)/\varepsilon(\mu^-\pi^+) + 1}$$

μπ Detection Asymmetries

Efficiency ratios:

$$\frac{\varepsilon(\mu^+\pi^-)}{\varepsilon(\mu^-\pi^+)} = \frac{N(D^0 \to K^-\mu^+\nu_\mu)}{N(\overline{D}^0 \to K^+\mu^-\overline{\nu}_\mu)} \times \frac{N(\overline{D}^0 \to K^+\pi^-)}{N(D^0 \to K^-\pi^+)}$$

μπ asymmetries:

$$A_{\mu\pi} = \frac{\varepsilon(\mu^+\pi^-)/\varepsilon(\mu^-\pi^+) - 1}{\varepsilon(\mu^+\pi^-)/\varepsilon(\mu^-\pi^+) + 1}$$

Not only track asymmetries:

$$A_{\mu\pi} = A_\mu^{\mathrm{ID}} + A_\mu^{\mathrm{trigger}} + A_\mu^{\mathrm{track}} + A_\pi^{\mathrm{track}} + A_\pi^{\mathrm{interaction}}$$

Detection asymmetries can depend on kinematics

→ reweight

Reweighting Strategy

Reweighting p_T and η in 3 steps:

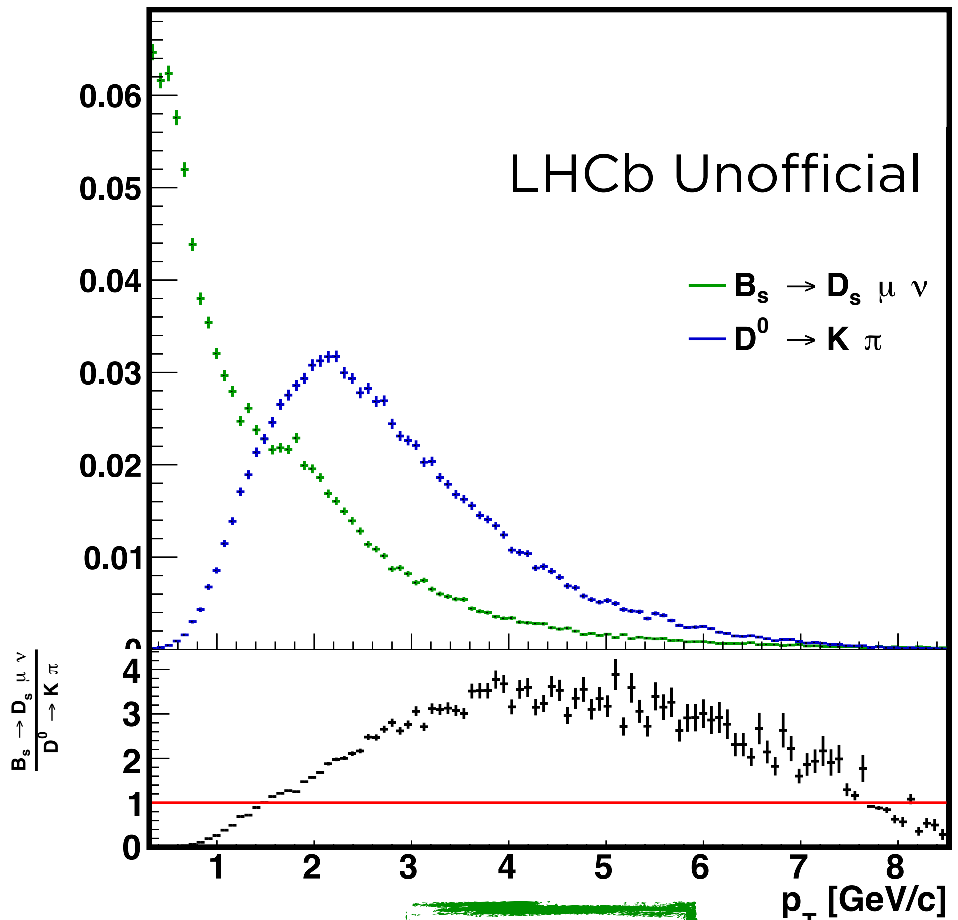
1. $D^{*+} \to D^0(K^- \boldsymbol{\pi^+})\pi_s^+$ to $\bar{B}_s^0 \to D_s^+(K^+K^- \boldsymbol{\pi^+})\mu^-\bar{\nu}$
2. $\boldsymbol{D^{*+}} \to D^0(\boldsymbol{K^-}\mu^+\nu)\pi_s^+$ to $\boldsymbol{D^{*+}} \to D^0(\boldsymbol{K^-}\pi^+)\pi_s^+$
3. $\bar{B}_s^0 \to D_s^+(K^+K^-\pi^+)\boldsymbol{\mu^-}\bar{\nu}$ to $D^{*-} \to D^0(K^+\boldsymbol{\mu^-}\bar{\nu})\pi_s^-$

For step 2 we need to use MC kinematics to compensate for the non-reconstructed neutrino.

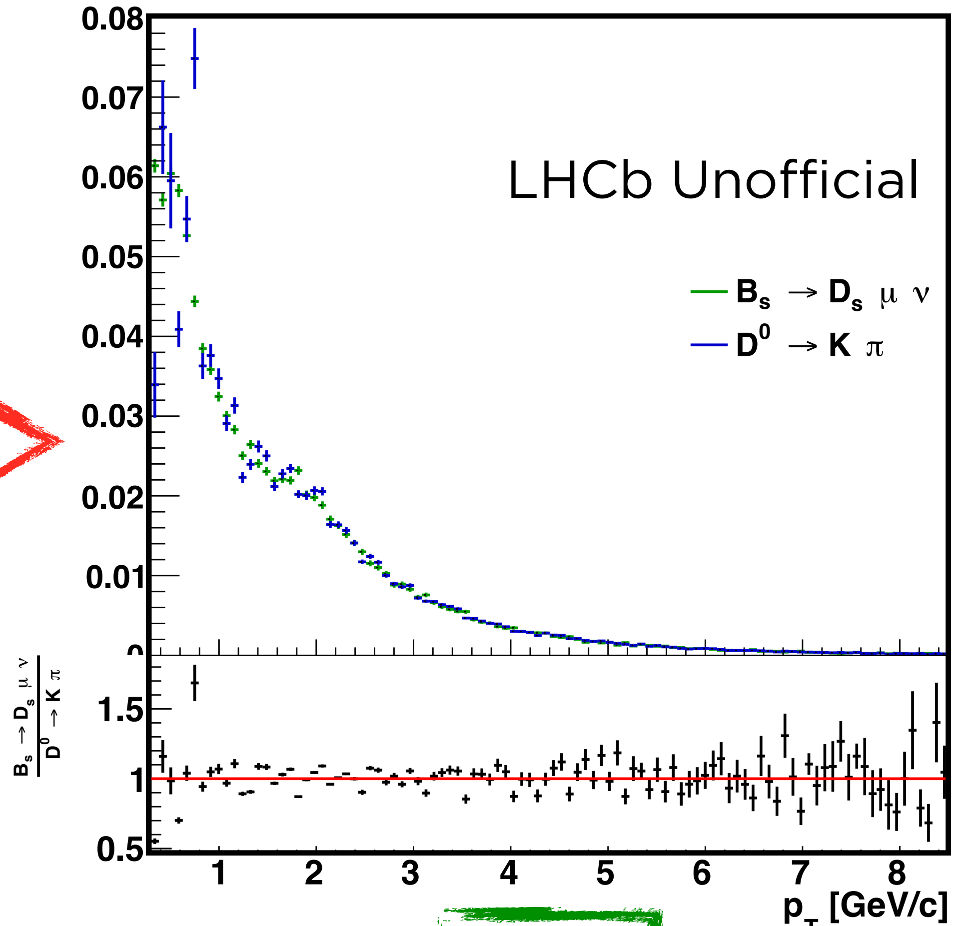
Example of Reweighting

π p_T distributions of $B_s \rightarrow D_s (\rightarrow K K$ **π** $) \mu \nu_\mu$

and $D^* \rightarrow D^0 (\rightarrow K$ **π** $) \pi_s$



Before



After

Conclusions

Semileptonic asymmetry:

$$a_{\rm sl} = \frac{\Gamma(\bar{B}_q \to B_q \to f) - \Gamma(B_q \to \bar{B}_q \to \bar{f})}{\Gamma(\bar{B}_q \to B_q \to f) + \Gamma(B_q \to \bar{B}_q \to \bar{f})}$$

Conclusions

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Most recent LHCb measurements:

$$a_{\mathrm{sl}}^s = (-0.06 \pm 0.50(\mathrm{stat}) \pm 0.36(\mathrm{syst}))\%$$

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$$a_{\mathrm{sl}}^d = (-0.02 \pm 0.19(\mathrm{stat}) \pm 0.30(\mathrm{syst}))\%$$

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In agreement with both SM and D0

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In agreement with both SM and D0

New $a_{\rm sl}^s$ analysis is on its way, including:

- extended phase space
- new methods to determine detection asymmetries

Outlook

$a_{\rm sl}^{s} = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\%$

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$a_{\rm sl}^{d} = (-0.02 \pm 0.19(\text{stat}) \pm 0.30(\text{syst}))\%$

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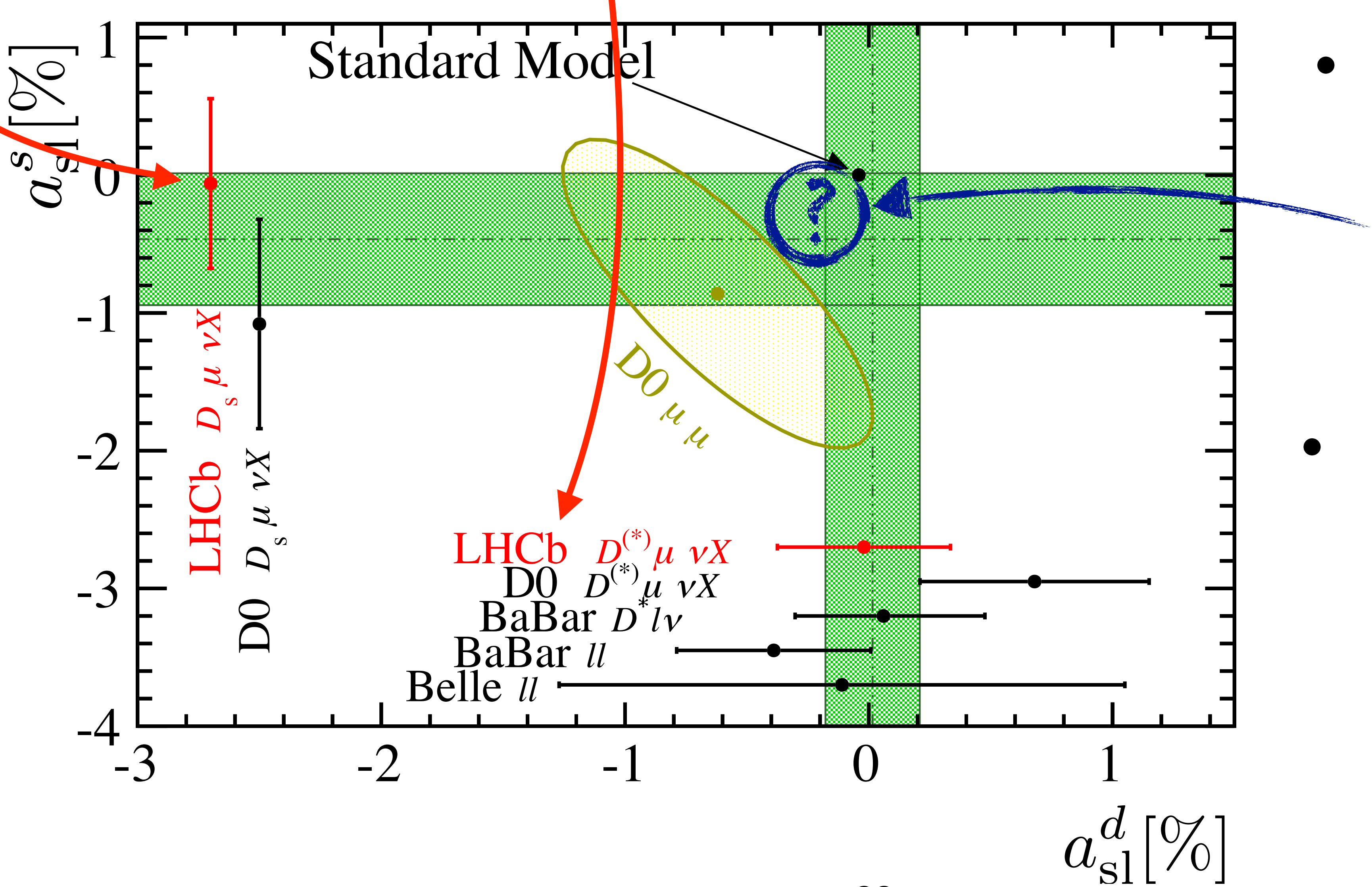

- By the end of LHCb Run-II: < 10^{-3} precision, for $a_{\rm sl}^{d}$ and $a_{\rm sl}^{s}$
- Able to exclude D0 and/or SM