CP violation in $B^0_{(s)} - \overline{B}^0_{(s)}$ mixing with semileptonic decays at LHCb

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on behalf of the LHCb collaboration

Heavy Quarks and Leptons 2016

Outline

- Introduction
- CPV in B^0 mixing (a_{sl}^d) 2015
- CPV in B_s mixing (a_{sl}^s)

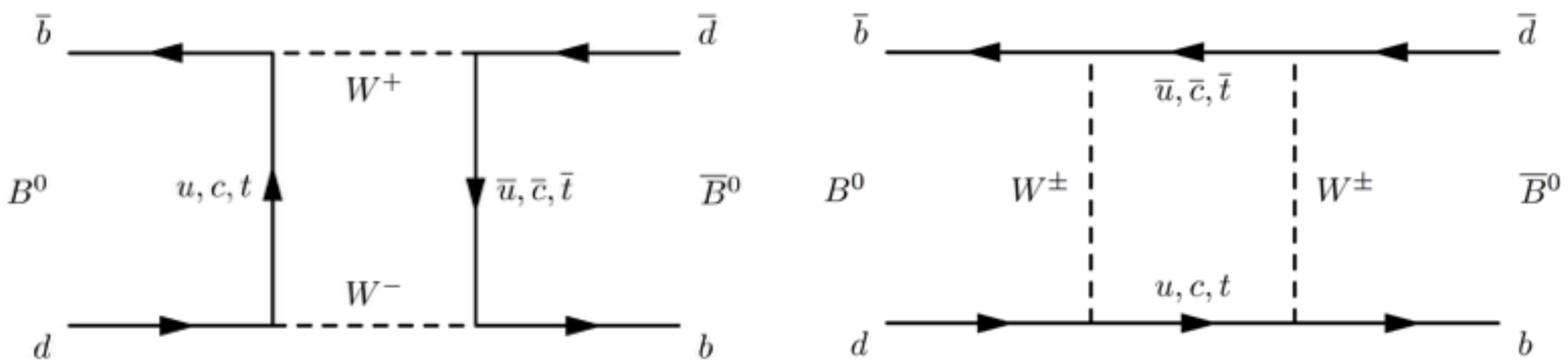
New preliminary result!

CPV in mixing

- Neutral B mesons: $|B^0_{H,L}\rangle = p|B^0_q\rangle \pm q|\overline{B}^0_q\rangle$

  $\longrightarrow$mass eigenstates $\neq$ flavor eigenstates

- $\Delta\Gamma$ and Δm$\longrightarrow$mixing



- CP violation in mixing: $P(B \to \overline{B}) \neq P(\overline{B} \to B)$

  $\longrightarrow |q/p| \neq 1$

The semileptonic CP asymmetry

- CP asymmetry in mixing: $P(B \to \overline{B}) \neq P(\overline{B} \to B)$

$$a_{sl}^{q} = \frac{\Gamma(\overline{B}(t) \to f) - \Gamma(B(t) \to \overline{f})}{\Gamma(\overline{B}(t) \to f) + \Gamma(B(t) \to \overline{f})} = \frac{1-(q/p)^4}{1+(q/p)^4} \approx \frac{\Delta\Gamma_q}{\Delta m_q} tan(\phi_{12}^{q})$$ (q=d,s)

- Inclusive semileptonic final state (flavor-specific)

$$\begin{tikzcd} B^0 \arrow[rr] & & f \\ \overline{B^0} \arrow[rr, "/" marking] \arrow[dr, bend right] & & f \\ & B^0 \arrow[ur, bend right] & \end{tikzcd}$$

- Two neutral B mesons

$\longrightarrow B^0 : a_{sl}^{d}$

$\longrightarrow B_s^0 : a_{sl}^{s}$

- From SM:

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

Artuso, Borissov, Lenz [arXiv:1511.09466]

Tiny! Possible enhancement from NP

Measuring a_{sl} at LHCb

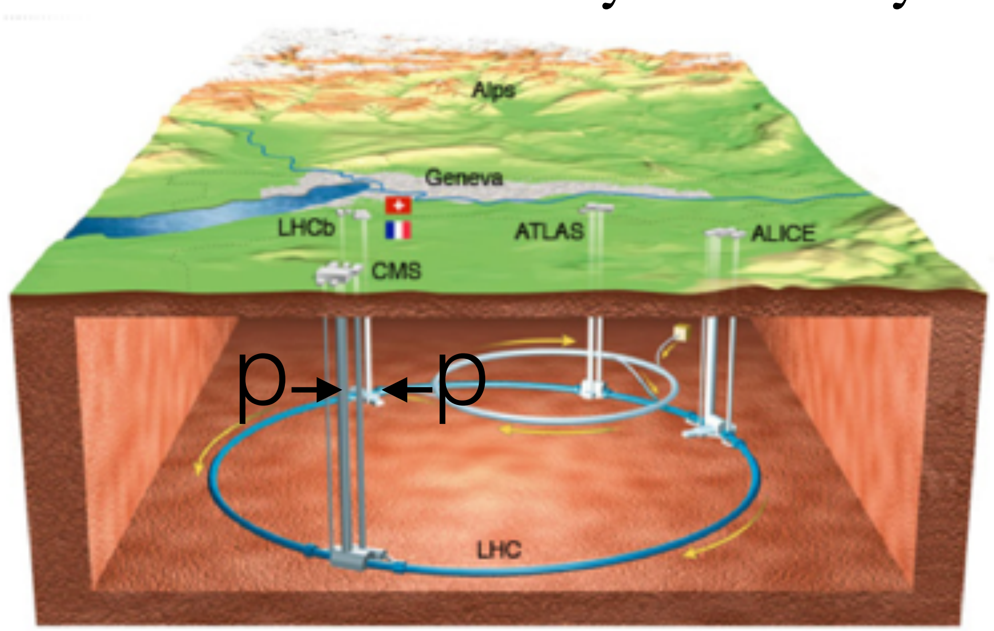
- Our measured quantity:

  $\longrightarrow$ Untagged (raw) charge asymmetry (ex. for B_s)

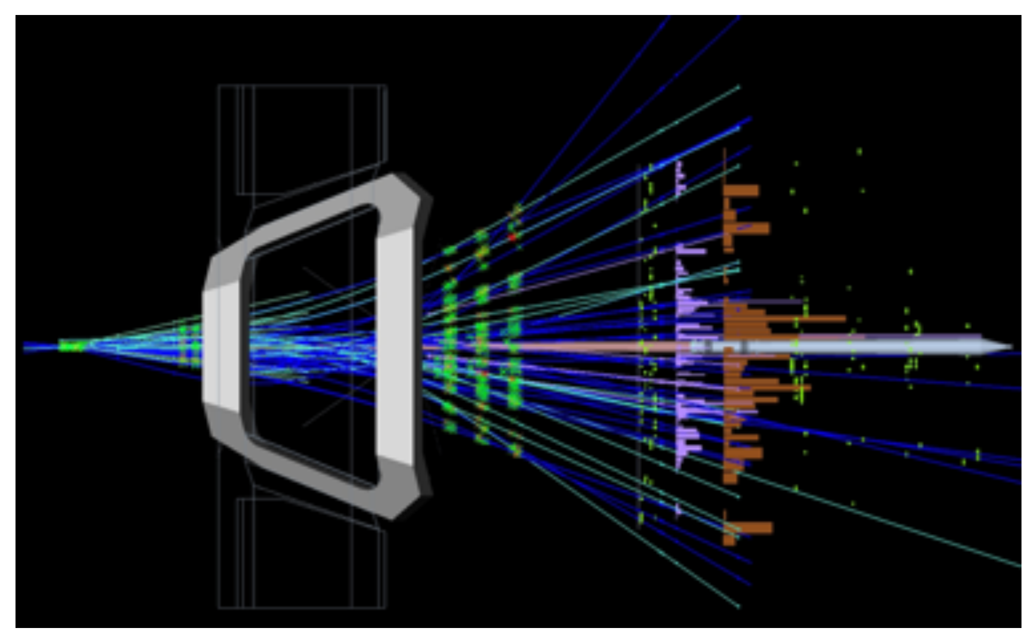
$$A_{raw} = \frac{N(D_s^-\mu^+) - N(D_s^+\mu^-)}{N(D_s^-\mu^+) + N(D_s^+\mu^-)} = \frac{a_{sl}^s}{2} - \frac{a_{sl}^s}{2}\frac{cos(\Delta m_s t)}{cosh(\Delta\Gamma_s t/2)}$$

…But there's more

Production asymmetry



Detection asymmetries



Measuring a_{sl} at LHCb

- Our measured quantity:
  - $\longrightarrow$ Untagged (raw) charge asymmetry (ex. for B_s)

$$\cancel{A_{raw} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-)}{N(D_s^- \mu^+) + N(D_s^+ \mu^-)} = \frac{a_{sl}^s}{2} - \frac{a_{sl}^s}{2} \frac{cos(\Delta m_s t)}{cosh(\Delta\Gamma_s t/2)}}$$

$$A_{raw} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-)}{N(D_s^- \mu^+) + N(D_s^+ \mu^-)} = \frac{a_{sl}^s}{2} + A_D + (A_P - \frac{a_{sl}^s}{2}) \frac{cos(\Delta m_s t)}{cosh(\Delta\Gamma_s t/2)}$$

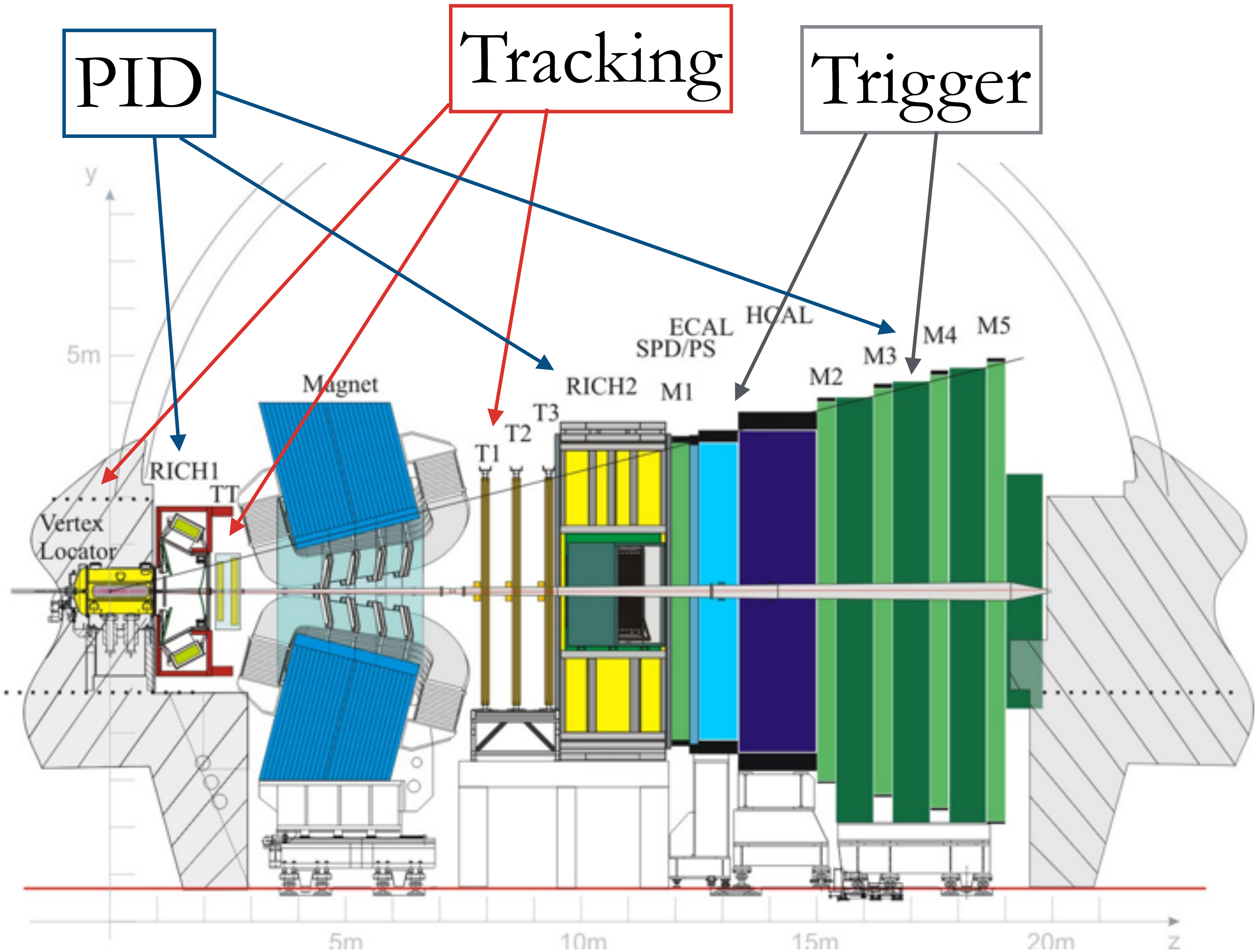
Detection asymmetry

Production asymmetry

Detection asymmetries

Int. J. Mod. Phys. A 30, 1530022 (2015)

- Large experimental challenge
- Assessed in data using calibration samples



$$a_{sl}^{d}$$

LHCb, PRL 114 (2015) 041601

a_{sl} in B^0

$$A_{raw} \approx \underbrace{A_D + \frac{a^d_{sl}}{2}}_{\text{Offset}} + \underbrace{(A_P - \frac{a^d_{sl}}{2})}_{\text{Amplitude}}\underbrace{cos(\Delta m_d t)}_{\text{Mixing term}}$$

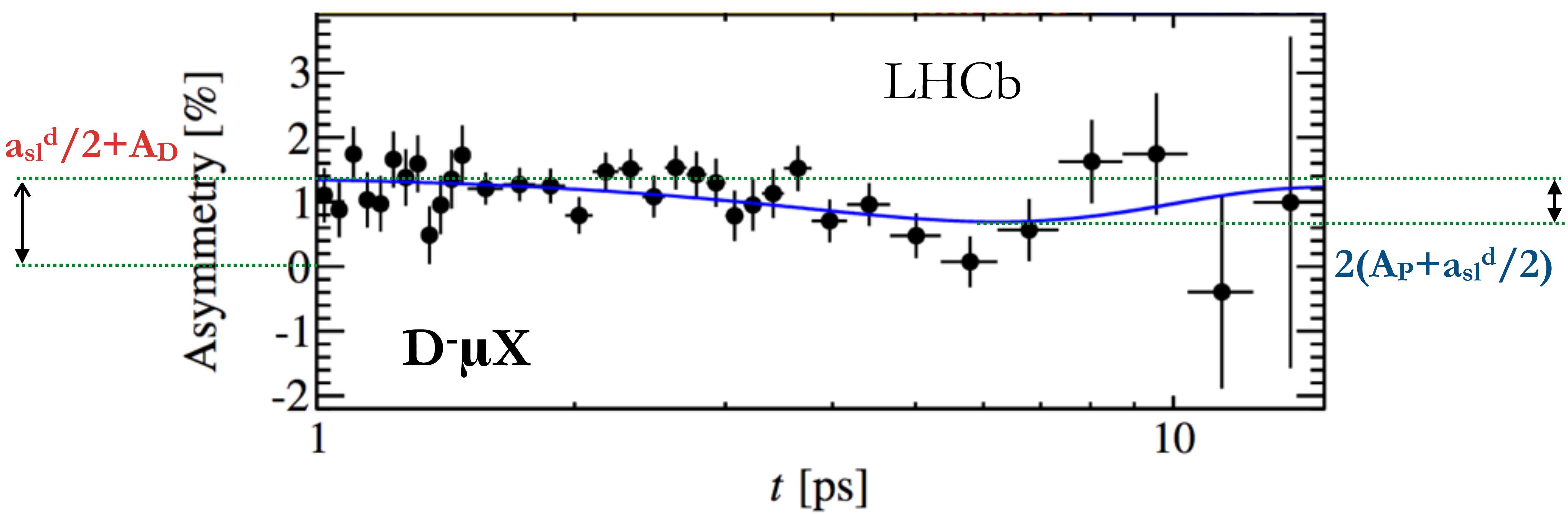
- $3fb^{-1}$ taken at 7TeV(2011) and 8TeV(2012)
- $B^0 \to D^{(*)-}\mu^+\nu X$ semileptonic decays
- 2D fit in $D^{(*)+}$ mass and B decay time

  ⟶ Correction for missing ν
- A_P and a_{sl}^d disentangled in A_{raw}

Results

$$A_{raw} \approx A_D + \frac{a_{sl}^d}{2} + (A_P - \frac{a_{sl}^d}{2})cos(\Delta m_d t)$$

Offset **Amplitude** **Mixing term**



Result: a_{sl}^d=(-0.02 ± 0.19(stat) ± 0.30(syst))%

The a_{sl} landscape so far

SM:

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

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

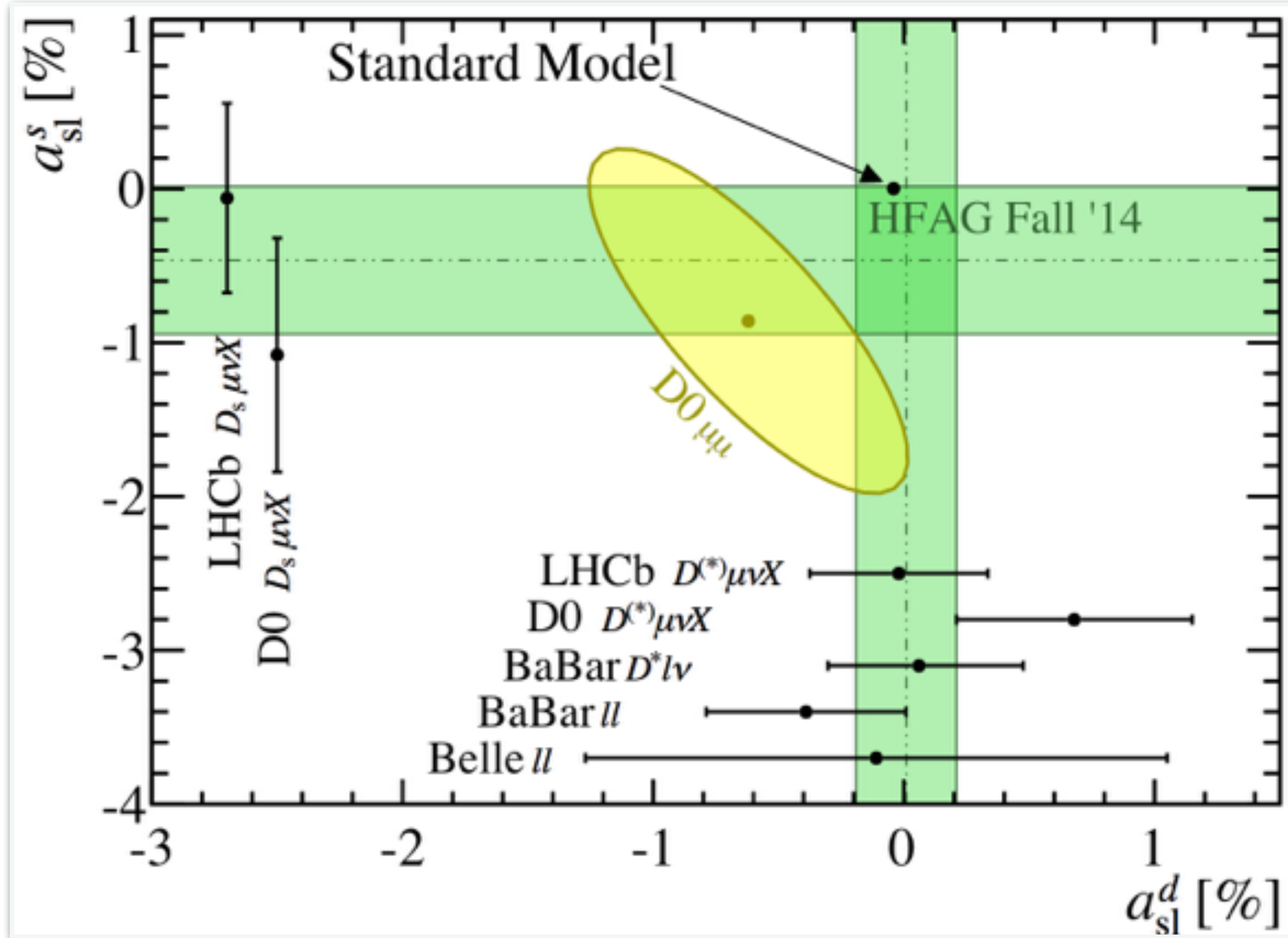
Artuso, Borissov, Lenz [arXiv:1511.09466]

HFAG:

$$a_{sl}^d = (0.01 \pm 0.20) \times 10^{-2}$$

$$a_{sl}^s = (-0.48 \pm 0.48) \times 10^{-2}$$

HFAG [arXiv:1412.7515]
*without D0 dimuon result
[PRD 89, 012002 (2014)]



LHCb:

$$a_{sl}^d = (-0.02 \pm 0.19(stat) \pm 0.30(syst)) \times 10^{-2}$$

$$a_{sl}^s = (-0.06 \pm 0.50(stat) \pm 0.36(syst)) \times 10^{-2}$$ (1fb^{-1})

LHCb, PRL 114, 041601 (2015)
LHCb, PLB 728C (2014) 607

D0, Phys. Rev. D 86, 072009
D0, Phys. Rev. Lett. 105, 081801
D0, Phys. Rev. D 82, 012003
BaBar, Phys. Rev. Lett. 111, 101802
BaBar, arXiv:1411.1842
Belle, Phys. Rev. D 73, 112002

$$a_{sl}^{s}$$

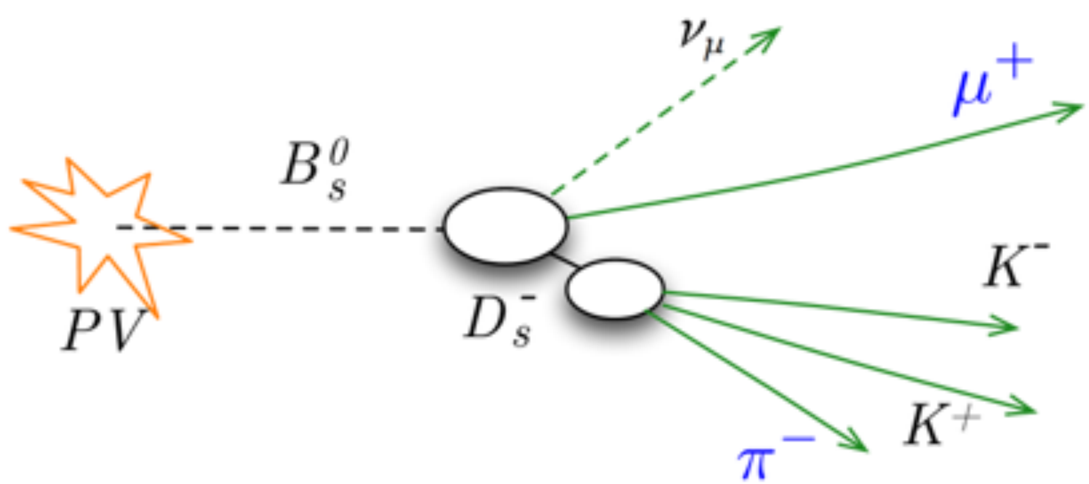
New preliminary result using full Run-I dataset (3fb^{-1})

LHCb-PAPER-2016-013

(To be submitted to PRL)

a_{sl} in B_s^0

- Inclusive $B_s^0 \to D_s^- \mu^+ \nu X$ decays



- Untagged, time integrated analysis

Integral O(10[-3]) due to rapid B_s oscillations

$$A_{raw} \approx A_D + \frac{a_{sl}^s}{2} + (A_P - \frac{a_{sl}^s}{2}) \int cos(\Delta m_s t) dt$$

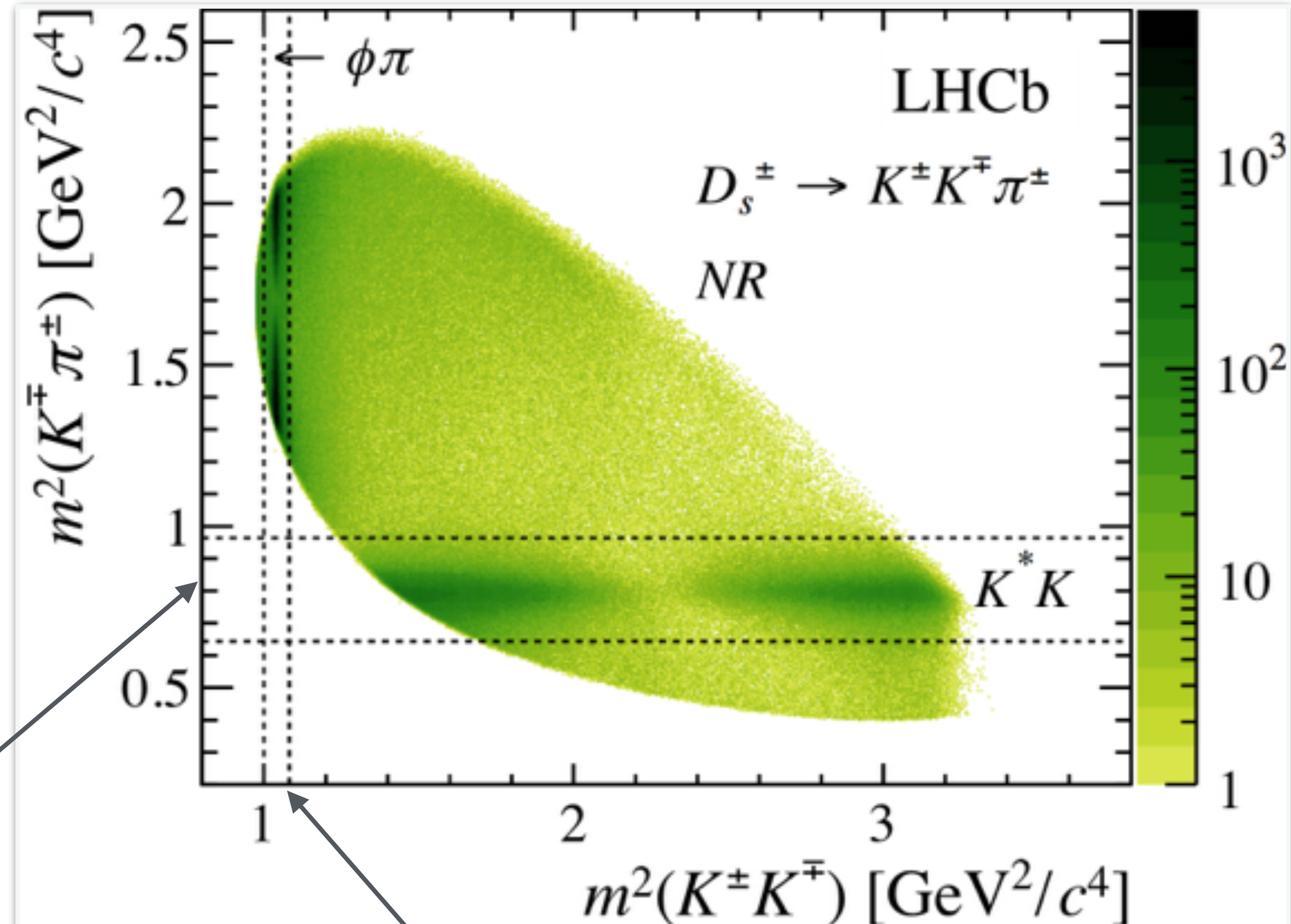
A_P O(10[-2])

- Adding backgrounds: $\frac{a_{sl}^s}{2} = \frac{1}{1 - f_{bkg}}(A_{raw} - A_D - f_{bkg} A_{bkg})$

D_s candidates

D_s split into 3 Dalitz regions

- Different levels of background
- Treated separately



m(Kπ)∈[806,986]MeV

m(KK)∈[1000,1040]MeV

Raw yields

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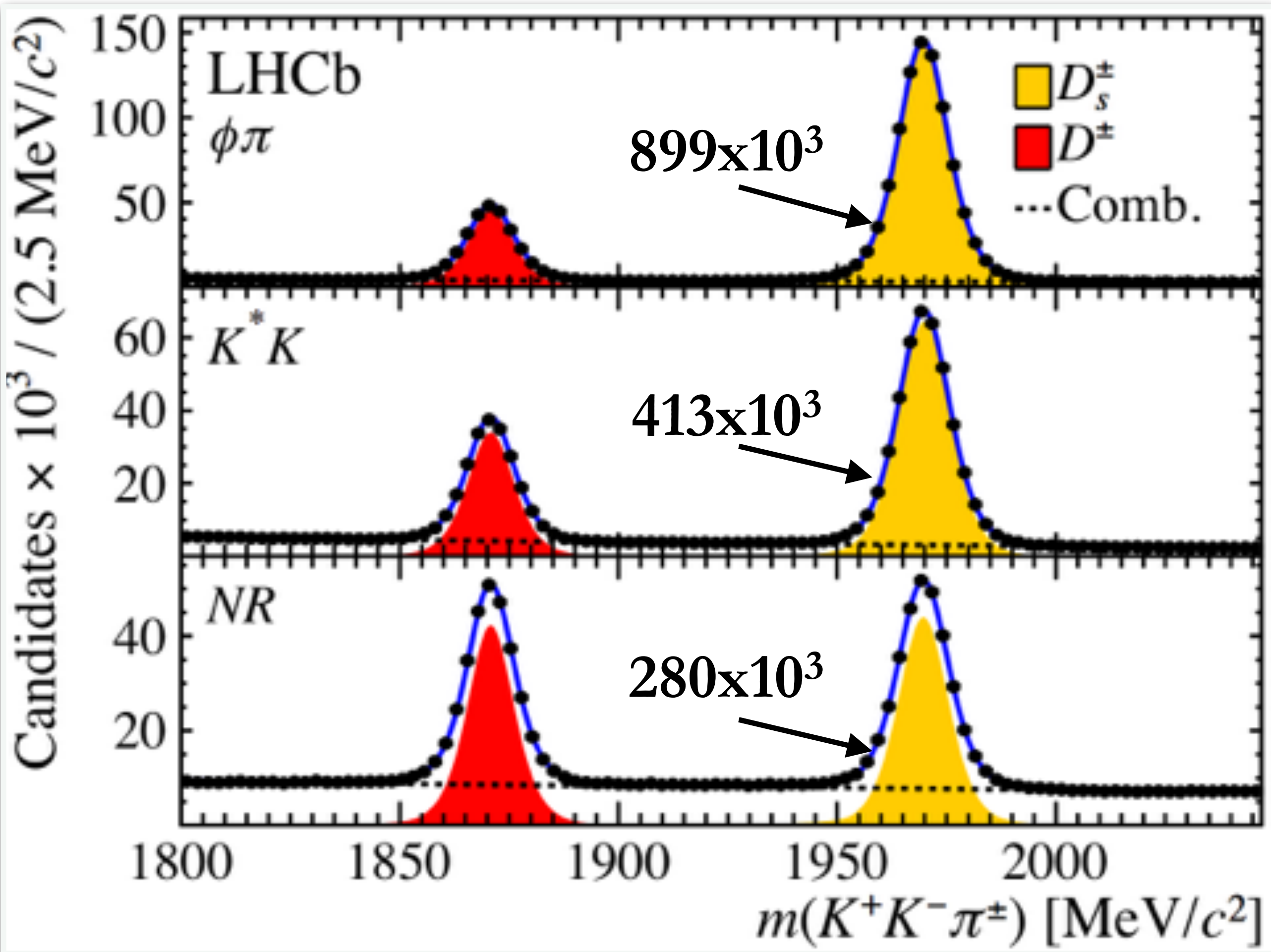
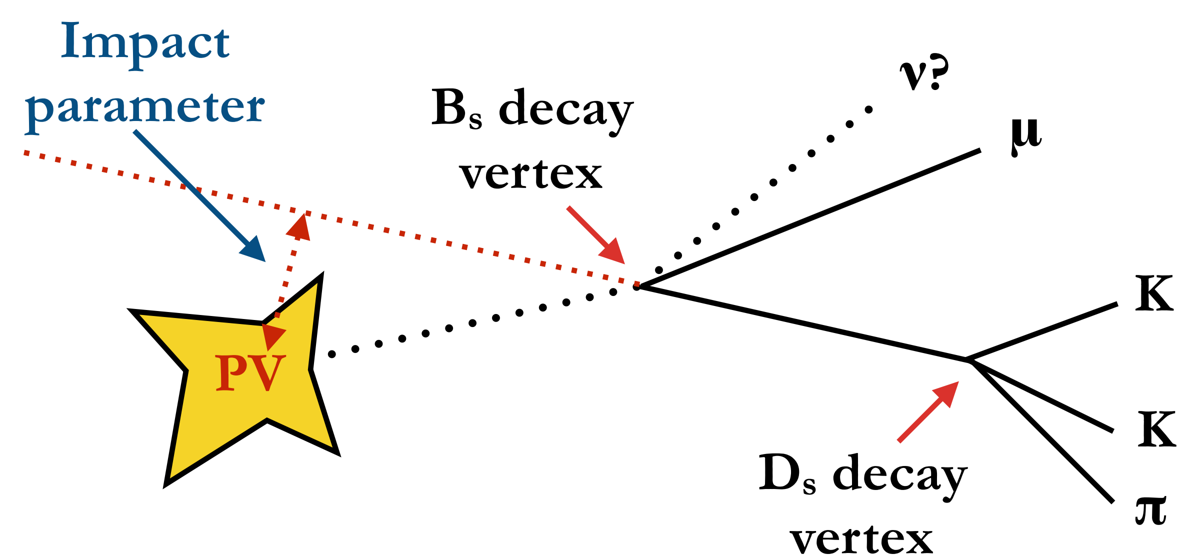
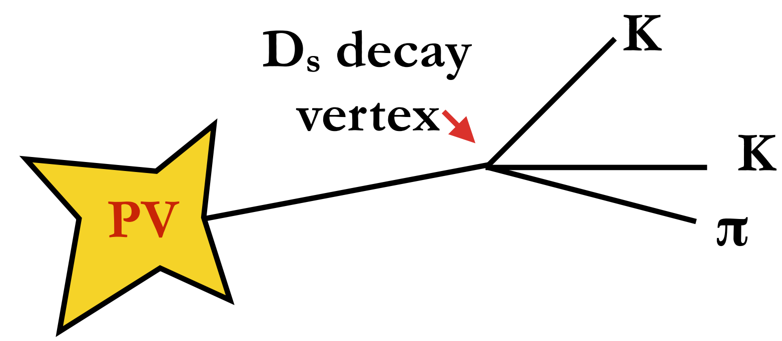


Signal topology



Directly produced D_s topology



- Select $D_s\mu$, fit D_s mass peak
- Directly produced D_s removed

  $\longrightarrow D_s$ impact parameter cut
- Fit contains peaking backgrounds

Peaking backgrounds

LHCb-PAPER-2016-013

- Peaking backgrounds dilute and bias measurement

$$\frac{a^s_{sl}}{2} = \boxed{\frac{1}{1-f_{bkg}}}\left(A_{raw} - A_D - \boxed{f_{bkg}A_{bkg}}\right)$$

- f_{bkg} from BRs and efficiency
- A_{bkg} mostly from production asymmetries

LHCb, JHEP 09 177 (2014)
LHCb, PRL 114, 041601 (2015)
LHCb, Chin.Phys.C 40, 1, 011001(2016)

$B^+ \to D^{(*)0} D_s^{(*)+} X$	"double-D"
$B^0 \to D^0 D_s^{(*)+} X$	
$B^0 \to D^- D_s^{(*)+} X$	
$B_s^0 \to D_s^{(*)-} D_s^{(*)+}$	
$\Lambda_b^0 \to \Lambda_c^+ D_s^{(*)+} X$	
$B^- \to D_s^+ K^- \mu^- \nu X$	"DsK"
$\overline{B}^0 \to D_s^+ K_S^0 \mu^- \nu X$	

$$f_{bkg} = (18.4 \pm 6.0)\%$$
$$\Sigma_i f^i_{bkg} A^i_{bkg} = f_{bkg} A_{bkg} = (-0.023 \pm 0.031)\%$$

Tracking asymmetry

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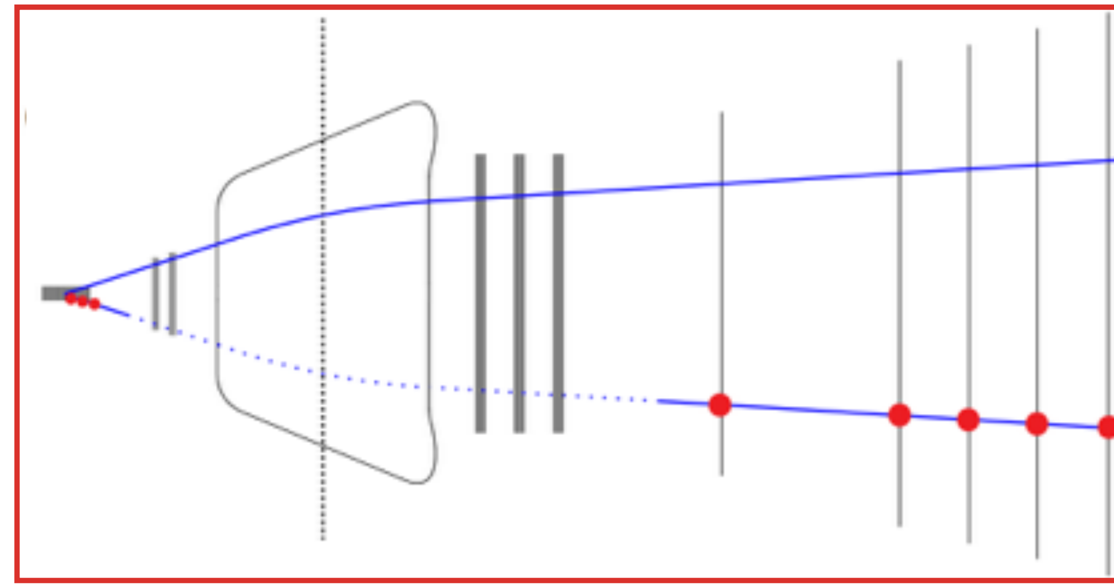
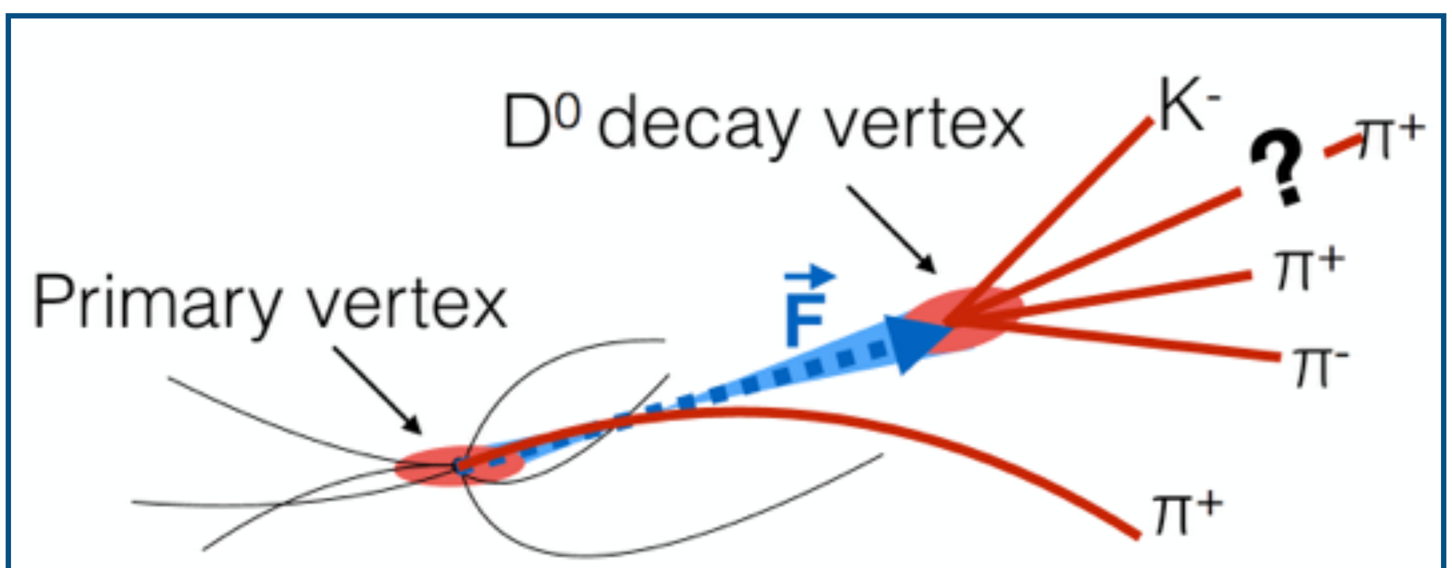
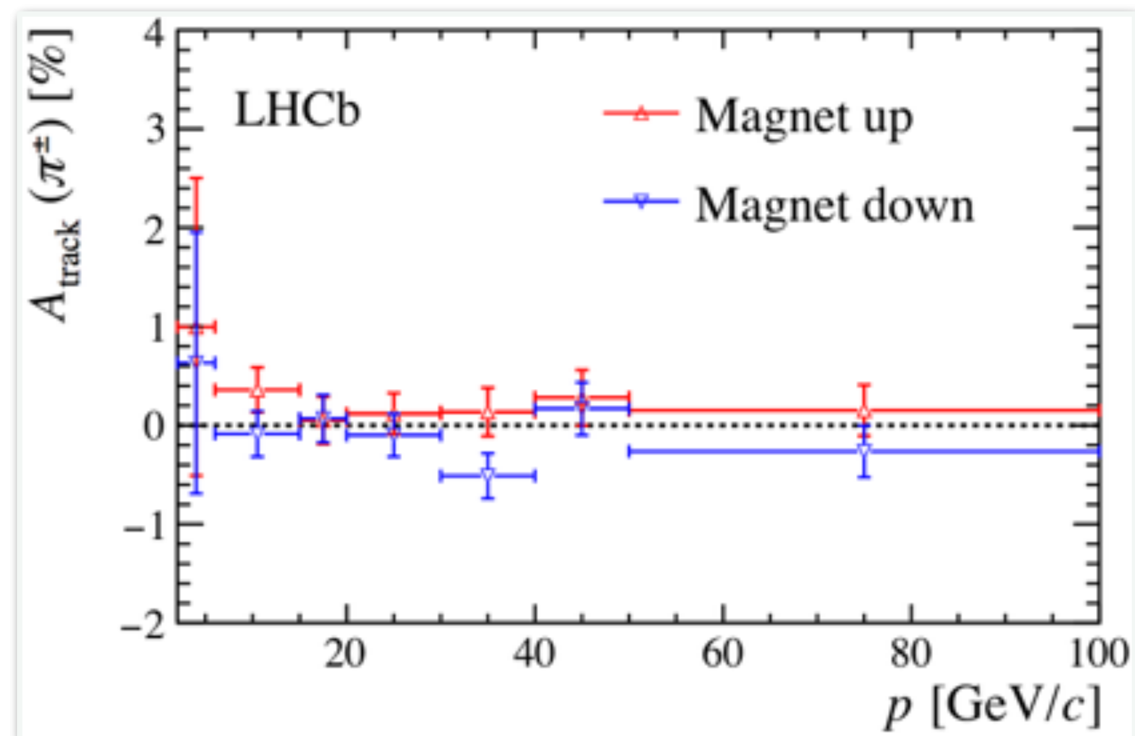
- Largest systematic in previous analysis
- Combine two methods
  - Tag-and-probe $J/\Psi \rightarrow \mu\mu$
  - Partially/fully reconstructed $D^{*+} \rightarrow D^0(\rightarrow K\pi\pi\pi)\pi$
- Simulation studies

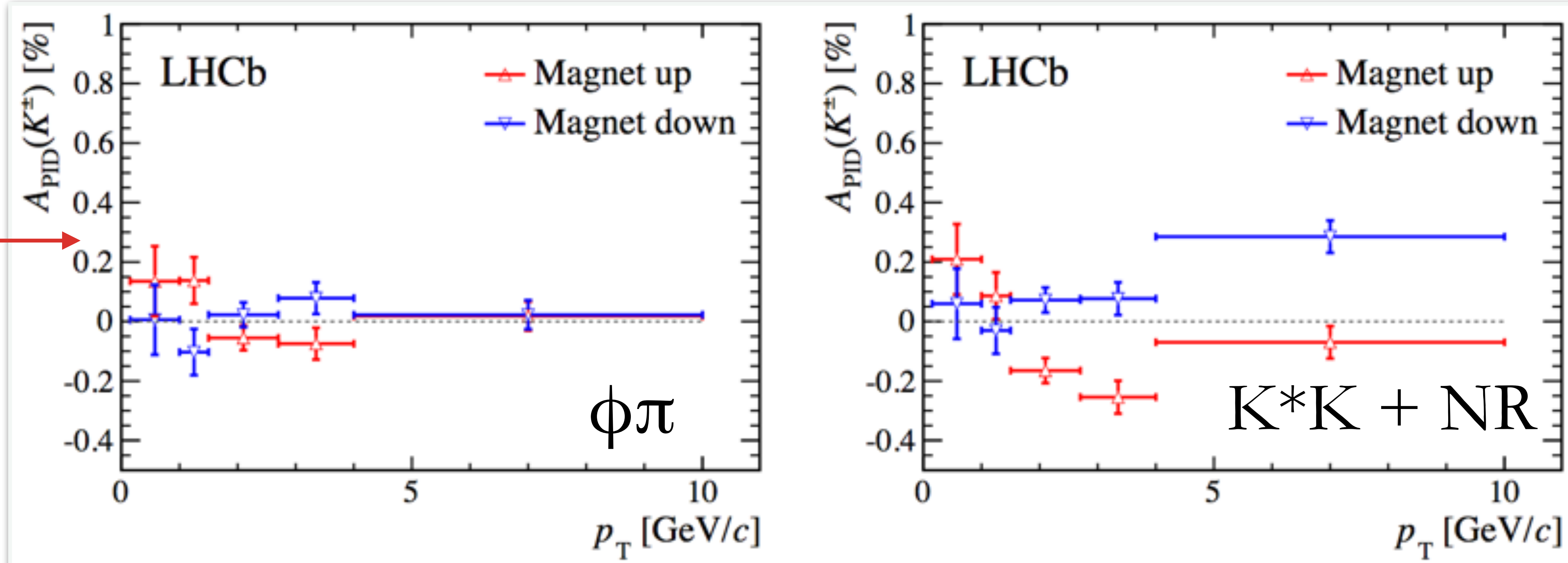




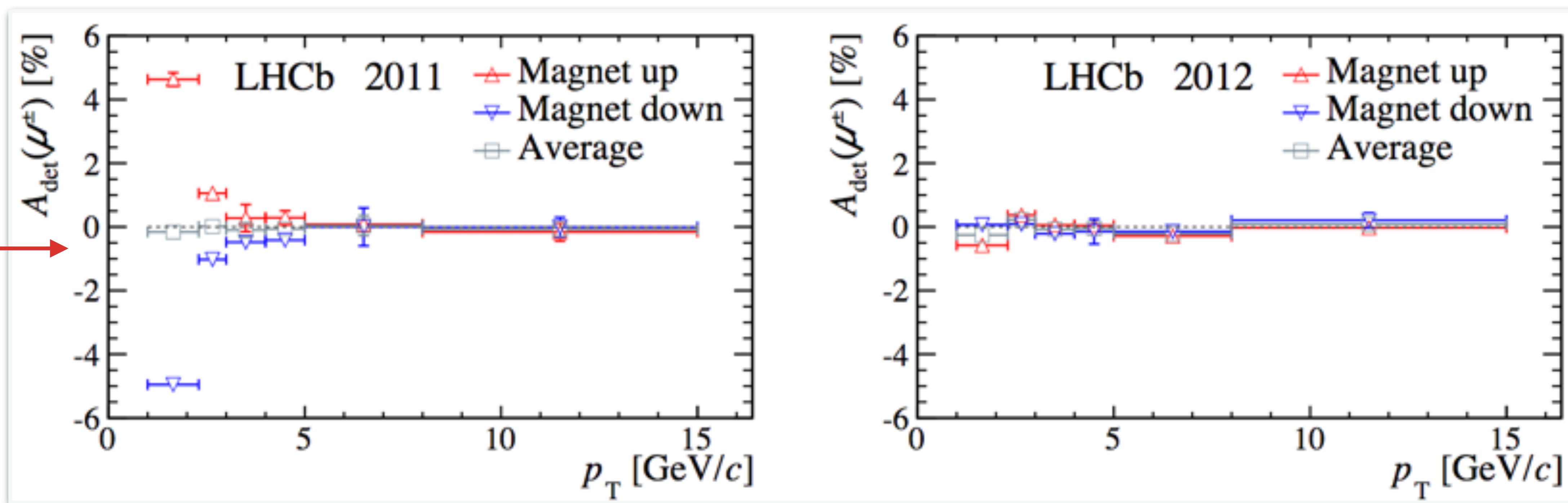


PID and trigger asymmetries

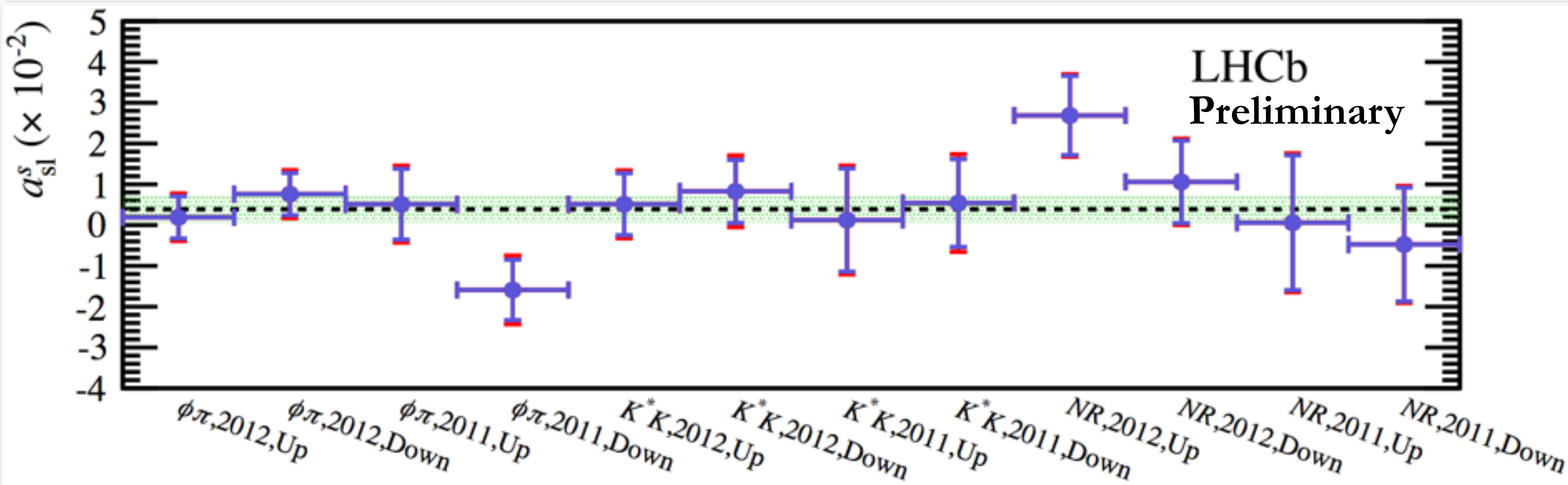
PID



Trigger



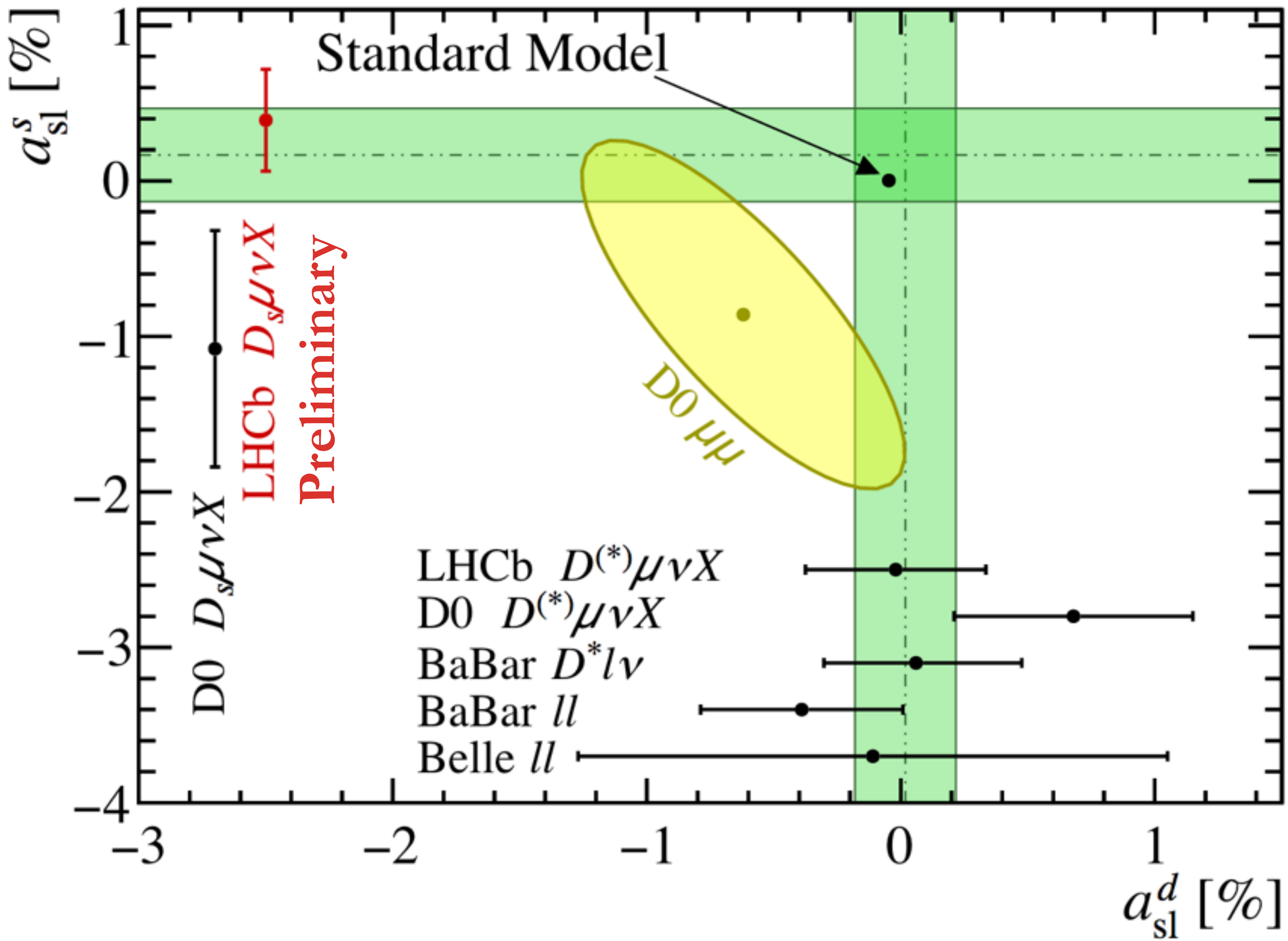
Results



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

Preliminary

The new a_{sl} landscape



Summary

- Measured a_{sl}^{d} and a_{sl}^{s} with the full Run-I LHCb dataset

$$a_{sl}^{d} = (-0.02 \pm 0.19(stat) \pm 0.30(syst)) \times 10^{-2}$$

$$a_{sl}^{s} = (0.39 \pm 0.26(stat) \pm 0.20(syst)) \times 10^{-2}$$

Preliminary result

- Most precise value of CPV in $B_{(s)}$ mixing to date
- Results compatible with SM prediction

Thank you!