Testing B-mesogenesis at LHCb

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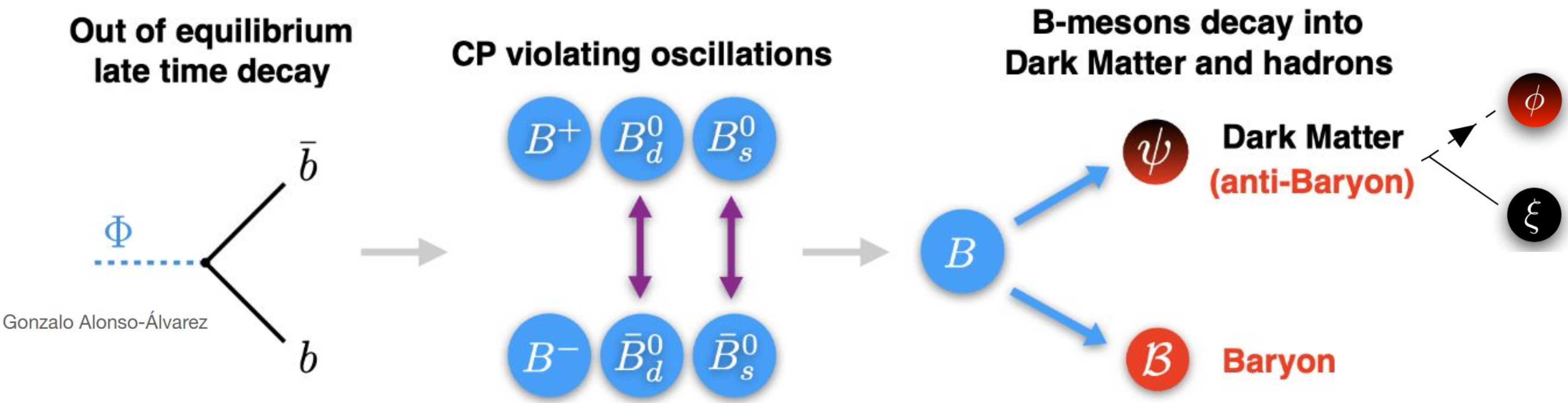
[1]On maternity leave

Introduction

B- mesogenesis: Alonso-Alvarez, Escudero, and Elor arXiv:2101.02706

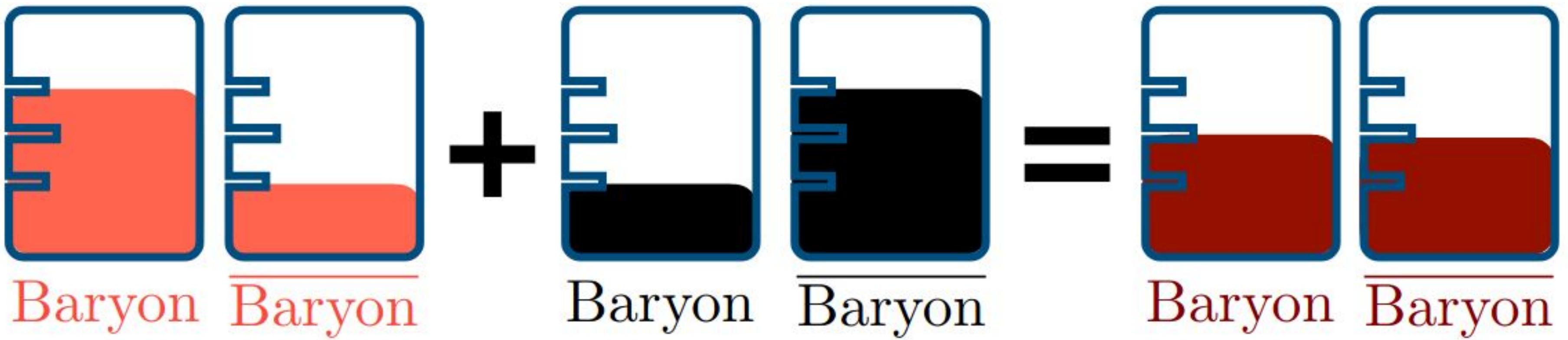


$T_R \sim 15\,\mathrm{MeV}$ $\quad A_{\mathrm{SL}}^d \;\; A_{\mathrm{SL}}^s \quad$ $\mathrm{Br}\left(B \to \psi + \mathcal{B} + \mathcal{M}\right)$

$$Y_{\mathcal{B}} \simeq 8.7 \times 10^{-11} \, \frac{\mathrm{Br}(B \to \psi + \mathcal{B} + \mathcal{M})}{10^{-2}} \sum_{q=s,d} \alpha_q \frac{A_{\mathrm{SL}}^q}{10^{-4}}$$

Introduction

Visible matter | **Dark matter** | **Universe**



Gonzalo Alonso-Álvarez

Similar spirit to Hylogenesis, Davoudiasl et al arxiV:1008.2399

$$Y_{\mathcal{B}} \simeq 8.7 \times 10^{-11} \frac{\mathrm{Br}(B \to \psi + \mathcal{B} + \mathcal{M})}{10^{-2}} \sum_{q=s,d} \alpha_q \frac{A_{\mathrm{SL}}^q}{10^{-4}}$$

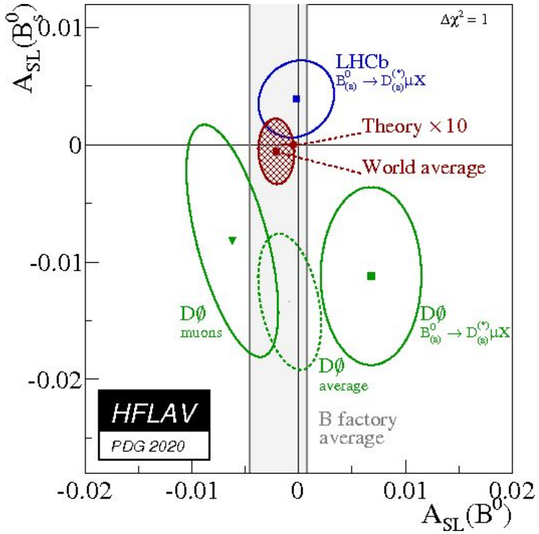
Ingredients for baryon asymmetry

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X)$$

Directly measured at LHCb and other experiments

At least one of the two A_{sl} needs to be **positive** to produce baryon abundance

Indirect determinations significantly favor a negative value for B_d, and in SM at least a **positive value for B_s** .



B$_d$: A_{SL} = −0.0021 ± 0.0017

B$_s$: A_{SL} = −0.0006 ± 0.0028

Ingredients for baryon asymmetry

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X)$$

Indirect determinations are in principle more precise

At least one of the two A_{sl} needs to be **positive** to produce baryon abundance

$$A_{SL}^{d}|_{SM} = (-4.7 \pm 0.4) \times 10^{-4}$$
$$A_{SL}^{s}|_{SM} = (2.1 \pm 0.2) \times 10^{-5}$$

Lenz & Tetlalmatzi-Xolocotzi 1912.07621

Indirect determinations significantly favor a negative value for B_d, and in SM at least a **positive value for** $\mathbf{B_s}$.

UTfit NP-fit 2018

A_{SL_d}	-0.0033 ± 0.0014
A_{SL_s}	-0.00013 ± 0.00051

→ ***B_s is the likeliest candidate for B-mesogenesis***

Ingredients for baryon asymmetry

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X) =$$

$$- \sum_{s,d} \left| \frac{\Delta\Gamma_{s,d}}{\Delta m_{s,d} \cos(\phi_{s,d} - \arg(\Gamma_{12}^{s,d}))} \right| \sin(\phi_{s,d} - \arg(\Gamma_{12}^{s,d}))$$

$$\times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X) \,,$$

Calculated in global fits (eg UTFit)

Very precise (~ 2 mrad) in SM and models w/o significant BSM contributions to ΔF = 1 penguins

Some theory work needed to compute it in the context of B-mesogenesis (e.g., whether it adds BSM contributions to ΔF = 1 penguins)

Ingredients for baryon asymmetry

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{\rm DS} X) =$$

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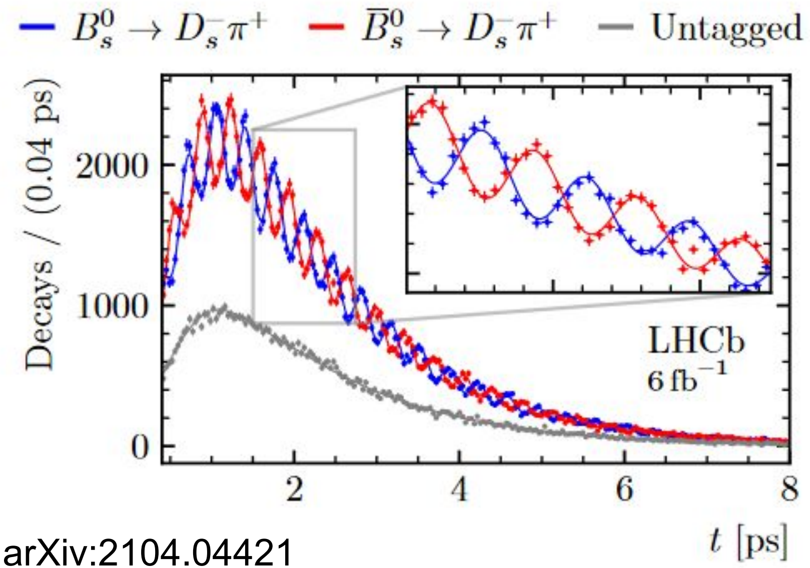
LHCb



arXiv:2104.04421

$\Delta m_s = 17.7656 \pm 0.0057$ ps^{-1}

Ingredients for baryon asymmetry

LHCb (& ATLAS/CMS)

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X) =$$

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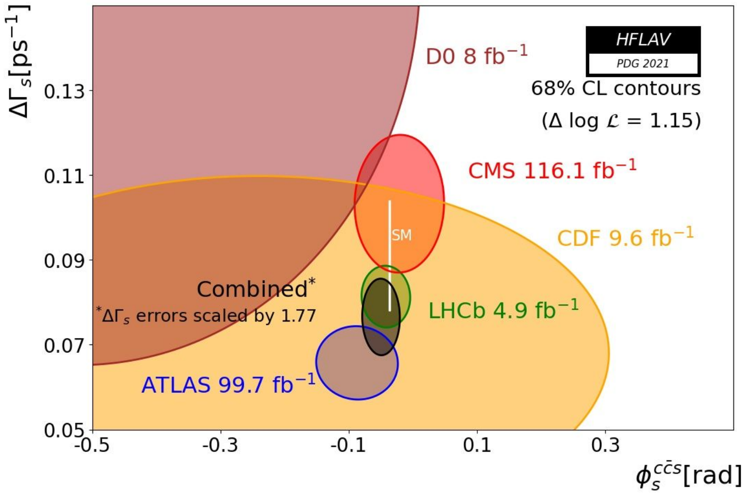


Ingredients for baryon asymmetry

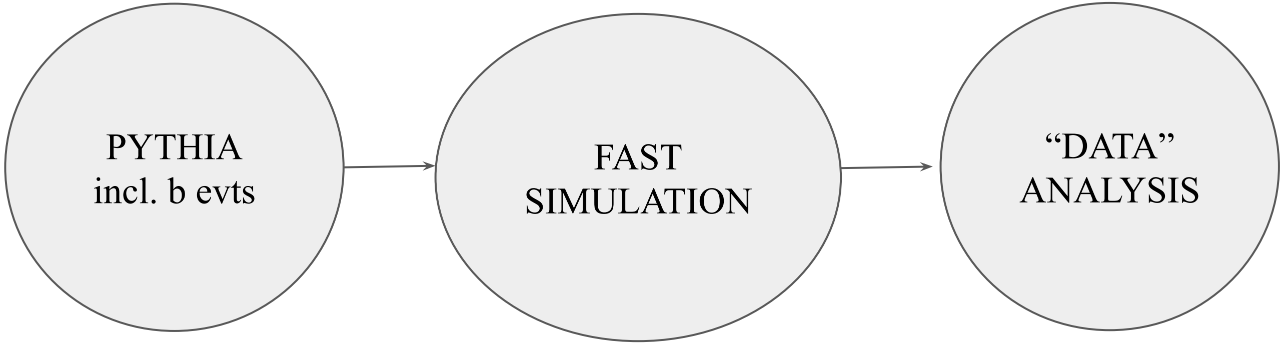
LHCb ? → this talk

$$Y_B \propto \sum_{s,d} A_{SL}^{s,d} \times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X) =$$

$$- \sum_{s,d} \left| \frac{\Delta\Gamma_{s,d}}{\Delta m_{s,d} \cos(\phi_{s,d} - \arg(\Gamma_{12}^{s,d}))} \right| \sin(\phi_{s,d} - \arg(\Gamma_{12}^{s,d}))$$

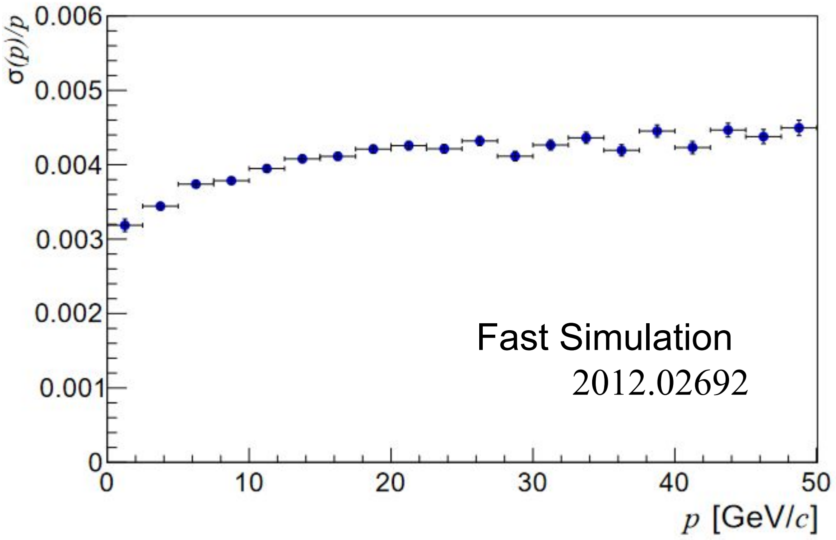
$$\times \mathscr{B}(B^0_{s,d} \to \psi_{DS} X)$$

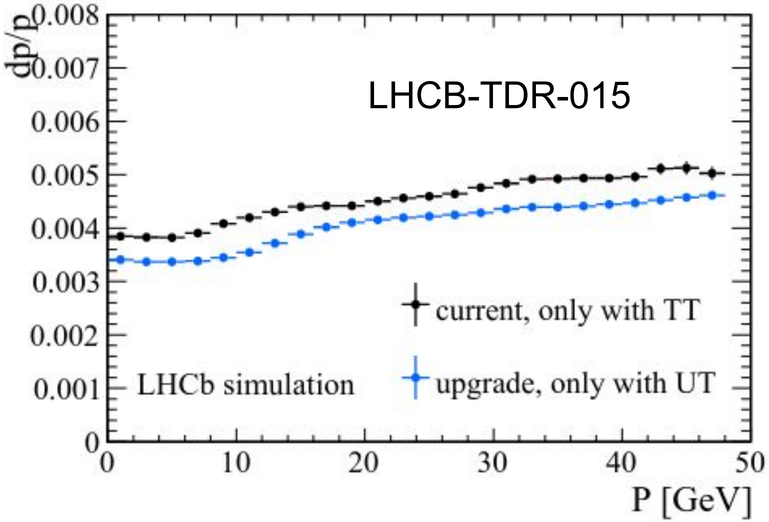
Setup



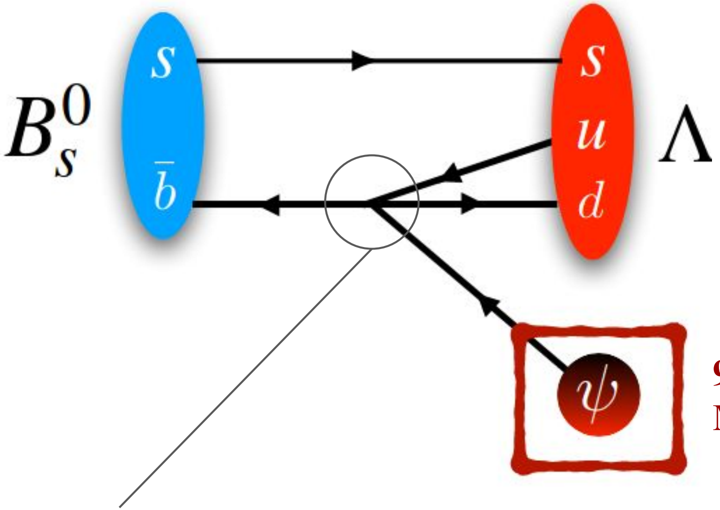
Setup: Fast simulation

- Fast simulation of the tracking system, including multiple scattering (V. Chobanova et al. 2012.02692)
- Particle identification from existing plots in LHCb papers/TDR's

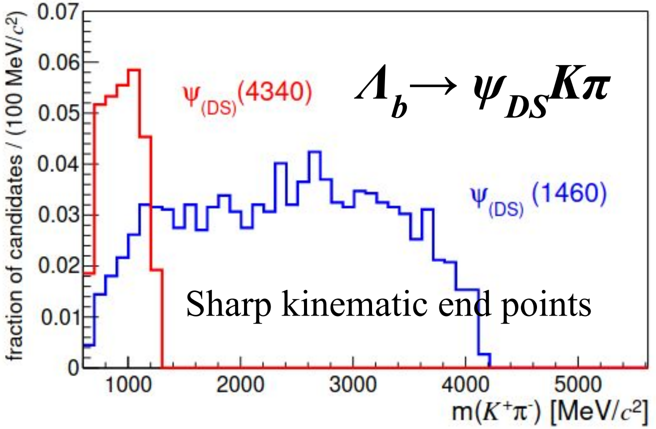


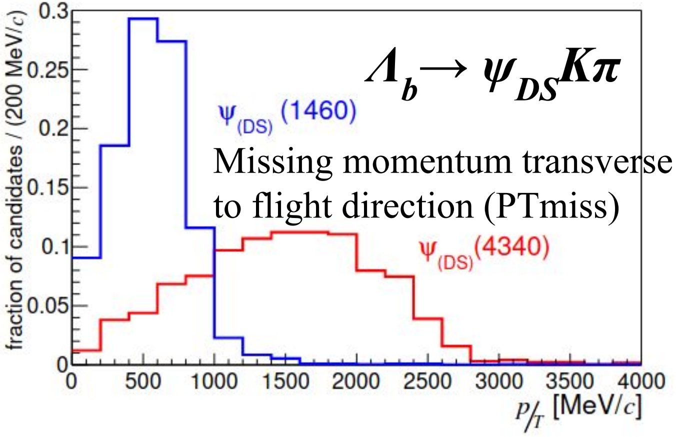


Signatures



940 - 4430 MeV



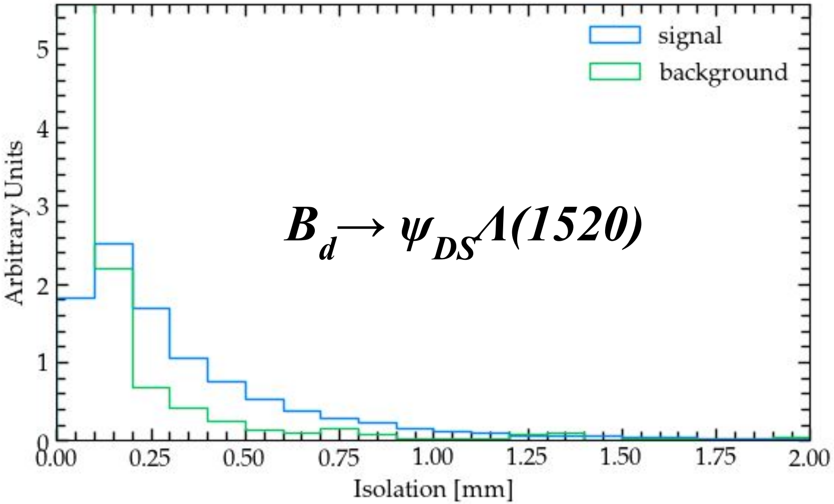


The b-quark decays, the other(s) are spectator
→ can be searched using **any of the b-hadron species, no need to restrict to Bs**

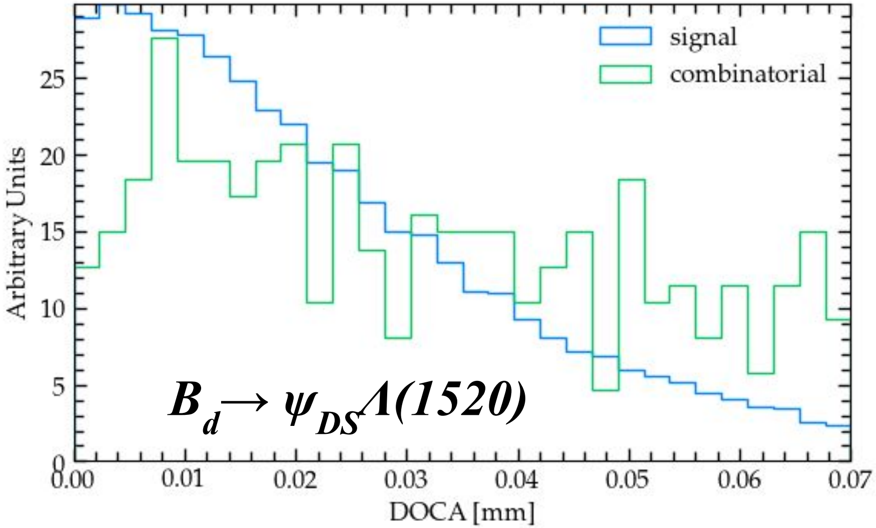
Inclusive BR's: ~ 0.1 - 0.001
Exclusive BR's: ~ 0.1 - 10^{-6}

Signatures

No tracks nearby



Daughter tracks close to each other (DOCA)



Usual requirements for b-daughter tracks: PT, detachment from PV.

Efficiencies

Decay mode	ε^{REC}%	$\varepsilon^{REC\&PT}$	$\varepsilon^{SEL/REC}$	$\varepsilon^{PID/SEL}$
$\Lambda_b^0 \to \psi_{DS}(940)K^+\pi^-$	7.6	5.1	13.2	74.2
$\Lambda_b^0 \to \psi_{DS}(940)\pi^+\pi^-$	7.3	4.8	14.3	-
$\Lambda_b^0 \to \psi_{DS}(1500)K^+\pi^-$	7.7	4.8	10.8	76.0
$\Lambda_b^0 \to \psi_{DS}(1500)\pi^+\pi^-$	7.3	4.5	12.5	-
$\Lambda_b^0 \to \psi_{DS}(2000)K^+\pi^-$	7.7	4.5	6.67	79.2
$\Lambda_b^0 \to \psi_{DS}(2000)\pi^+\pi^-$	7.4	4.1	10.9	-
$\Lambda_b^0 \to \psi_{DS}(2400)K^+\pi^-$	7.8	4.1	9.11	80.8
$\Lambda_b^0 \to \psi_{DS}(2400)\pi^+\pi^-$	7.4	3.7	8.89	-
$\Lambda_b^0 \to \psi_{DS}(4340)K^+\pi^-$	8.1	1.2	3.12	88.0
$\Lambda_b^0 \to \psi_{DS}(4340)\pi^+\pi^-$	7.4	0.97	2.88	-
$\Lambda_b^0 \to \psi_{DS}(4470)K^+\pi^-$	8.2	0.91	2.18	87.7
$\Lambda_b^0 \to \psi_{DS}(4470)\pi^+\pi^-$	7.4	0.79	2.23	-
$B^+ \to \psi_{DS}(940)\Lambda_c(2595)^+$	5.7	1.3	20.9	56.7
$B^+ \to \psi_{DS}(1500)\Lambda_c(2595)^+$	5.6	1.1	19.3	56.6
$B^+ \to \psi_{DS}(2000)\Lambda_c(2595)^+$	5.3	0.88	18.5	57.2
$B^+ \to \psi_{DS}(2400)\Lambda_c(2595)^+$	4.9	0.66	16.4	57.1
$B^0 \to \psi_{DS}(940)\Lambda(1520)$	13.3	12.7	38.1	56.9
$B^0 \to \psi_{DS}(1500)\Lambda(1520)$	13.7	12.9	36.6	56.4
$B^0 \to \psi_{DS}(2000)\Lambda(1520)$	13.5	12.6	35.5	56.8
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Used 4 signal decays

$$\Lambda_b \to \psi_{DS} K\pi$$
$$\Lambda_b \to \psi_{DS} \pi\pi$$

$$B_d \to \psi_{DS} \Lambda(1520)$$
$$B^+ \to \psi_{DS} \Lambda_c(2595)^+$$

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Reconstruction efficiency (including detector acceptance), in %

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Reconstruction efficiency
(including detector acceptance),
in %,
& 2 tracks with PT > 800 MeV

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Selection efficiency for those reconstructed events.
Selection includes PT cuts, vertex quality, isolation…

Not yet PT miss or invariant mass

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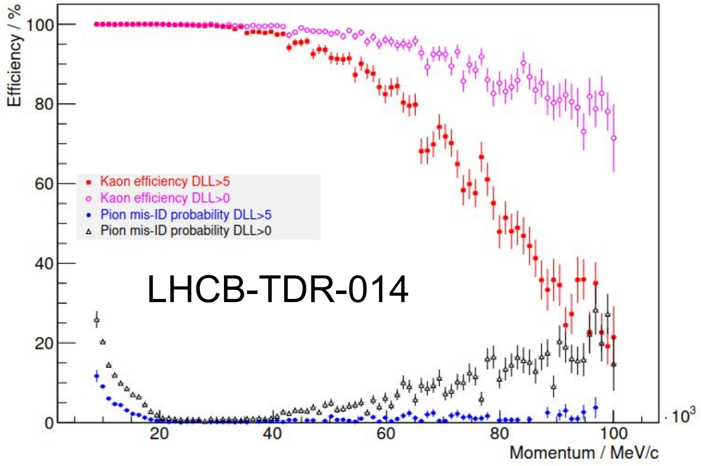
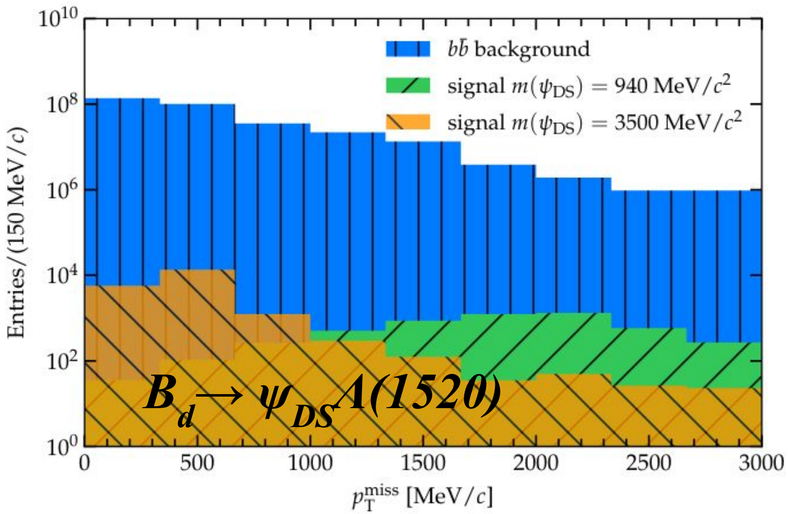
$B^0 \to \psi_{DS}(2000)\Lambda(1520)$	13.5	12.6	35.5	56.8
$B^0 \to \psi_{DS}(2400)\Lambda(1520)$	13.3	6.8	34.5	56.6
$B^0 \to \psi_{DS}(3500)\Lambda(1520)$	12.1	3.5	23.6	56.5

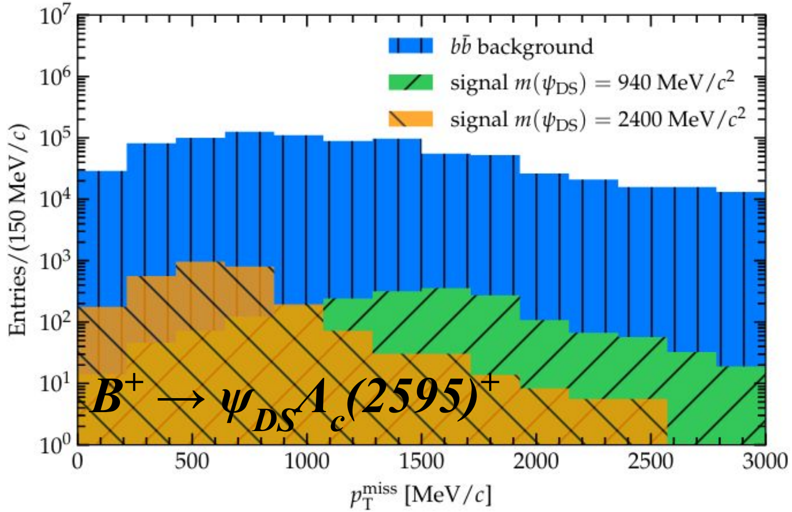
Particle Identification efficiency for selected events (Separation of Kaon/proton vs pion)



LHCB-TDR-014

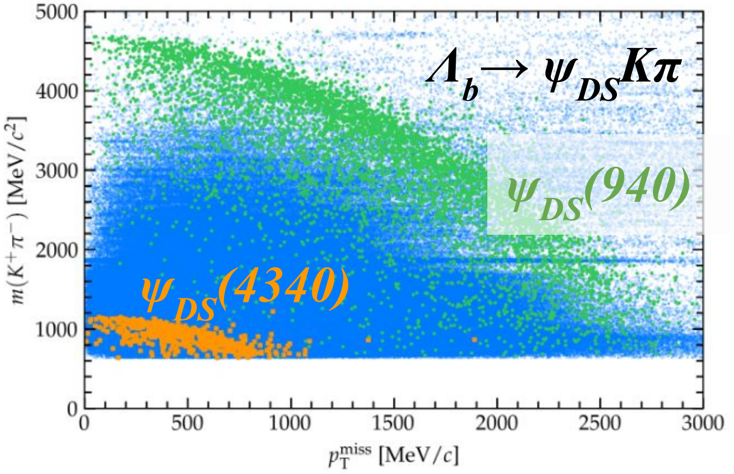
$B_d \rightarrow \psi_{DS} \Lambda(1520)$, $B^+ \rightarrow \psi_{DS} \Lambda_c(2595)^+$

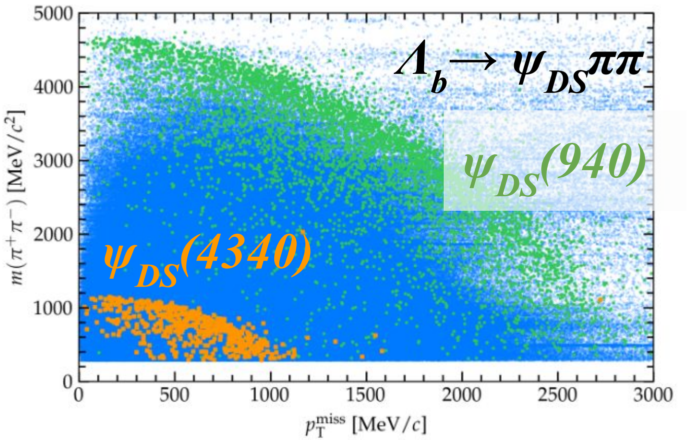




→ Search for signal in bins of PTmiss assuming BKG level is known

$\Lambda_b \to \psi_{DS} K\pi$, $\Lambda_b \to \psi_{DS} \pi\pi$

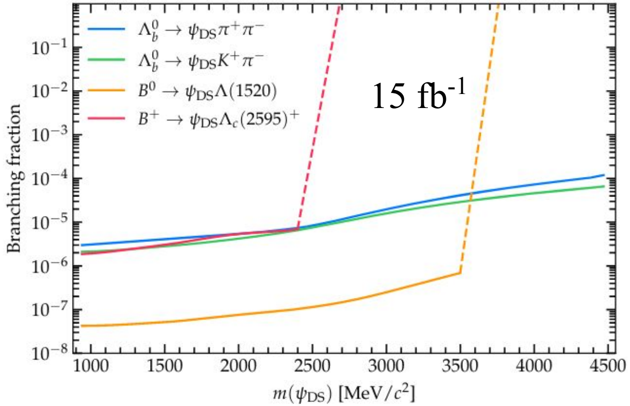




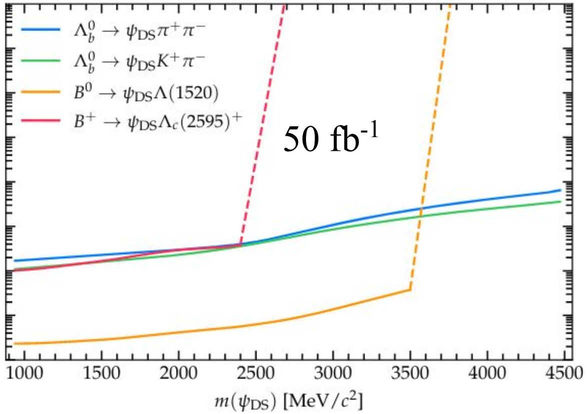
→ MVA combining M(h,h) & PTmiss

→ Optimize cut and search for signal assuming BKG level is known

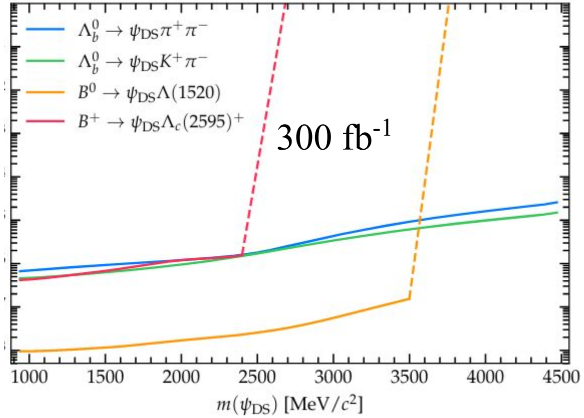
Sensitivity



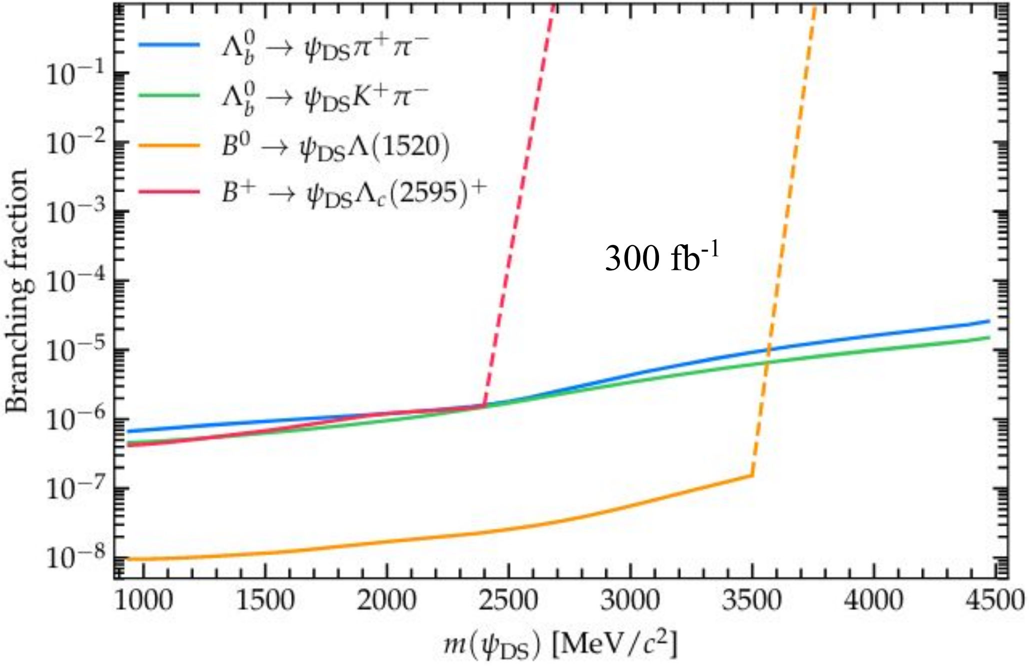
LHCb Upgrade
(Phase-I)



LHCb Upgrade
(Phase-II)



Sensitivity

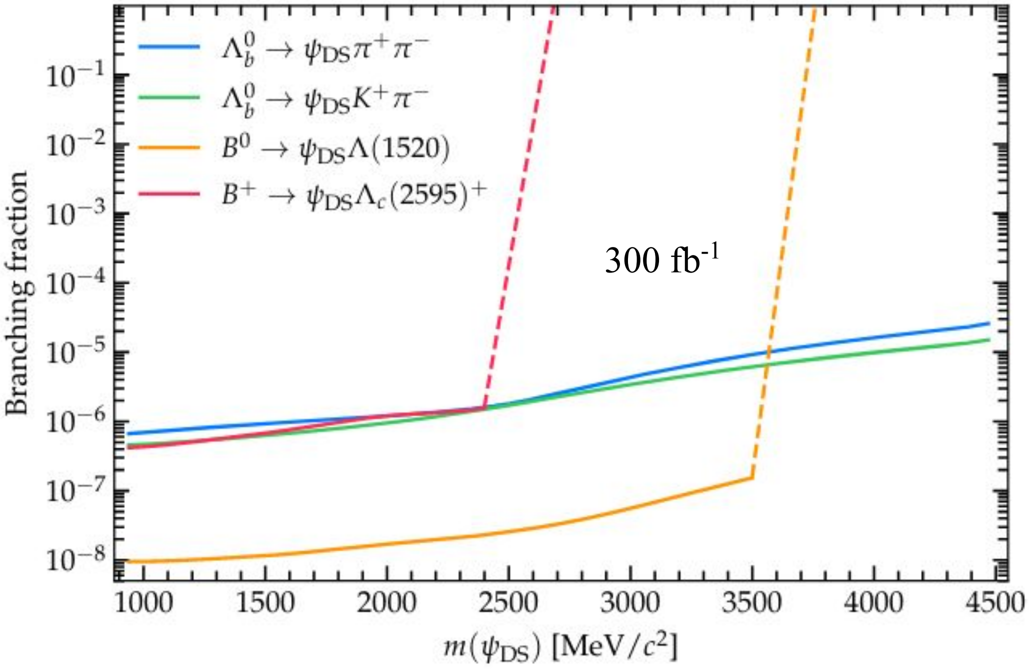


→ Signals are cleaner at low masses of the ψ_{DS} for the same BR → stronger BR limits at low masses

→ On the other hand, if ψ_{DS} is heavy, the exclusive BR's are higher → no need to go to so low BR to probe the theory

→ In terms of sample size, LHCb Upgrade can probe all allowed mass range for ψ_{DS}

Comment on systematics



A crucial difference w.r.t other searches os the extremely high background level

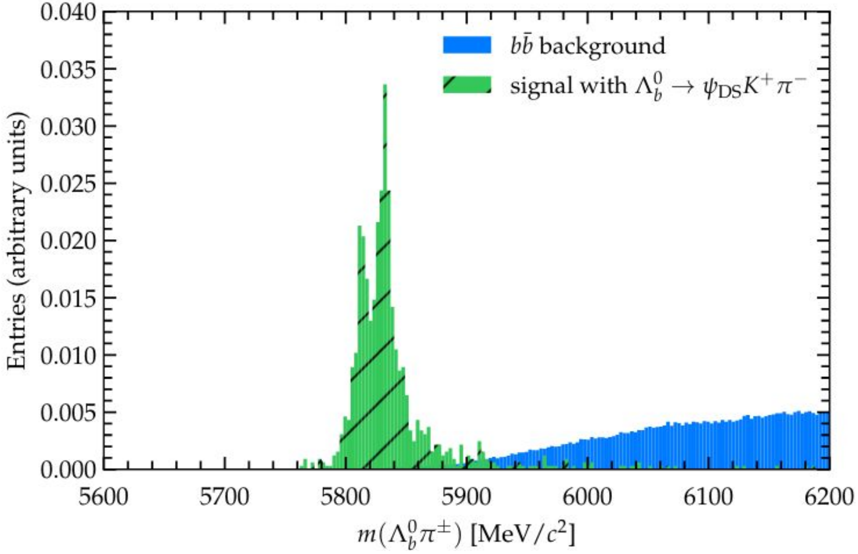
→ Even with small (per mil) systematics the measurement would be systematically limited after 10 fb^{-1}

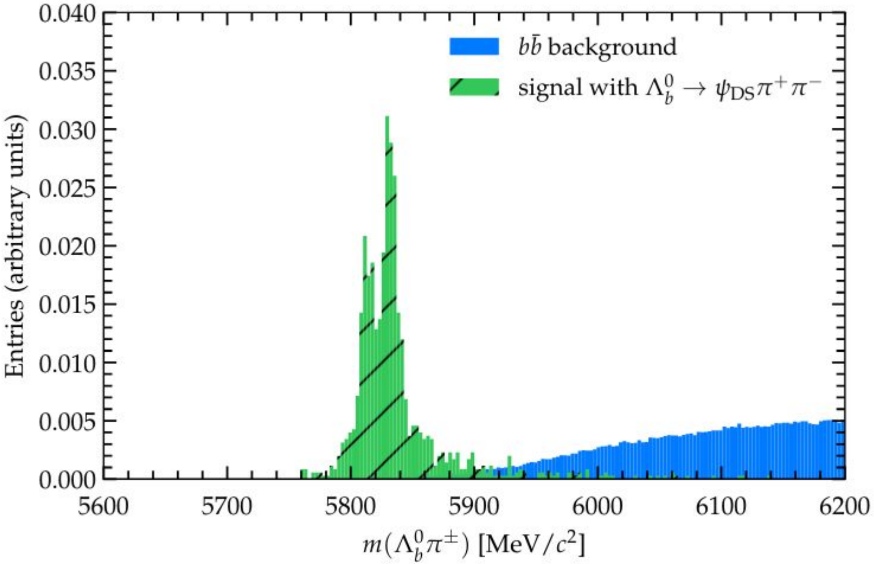
→ In terms of sample size, LHCb Upgrade can probe all allowed mass range for ψ_{DS}

→ LHCb Upgrade needs very precise bkg systematic (and/or stronger bkg suppression) to probe all allowed mass range for ψ_{DS}

Use of mother resonance?

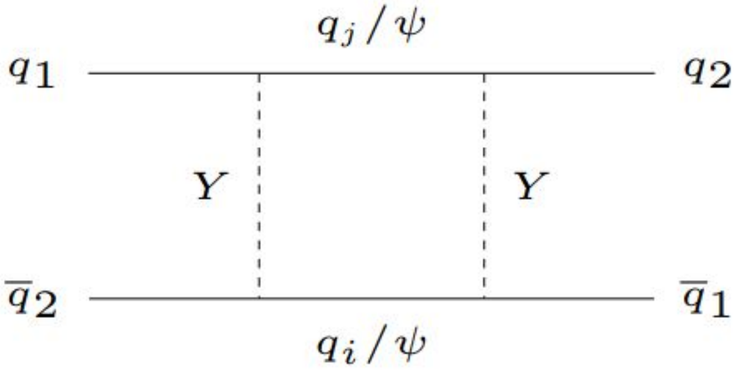
Further bkg suppression (as well as a clean signal peak confirmation) can be achieved by identifying the mother of the decaying b-handron (eg , $\Sigma_b^+ \rightarrow \Lambda_b \pi^+$) (see Zhang&Stone, 1402.4205)

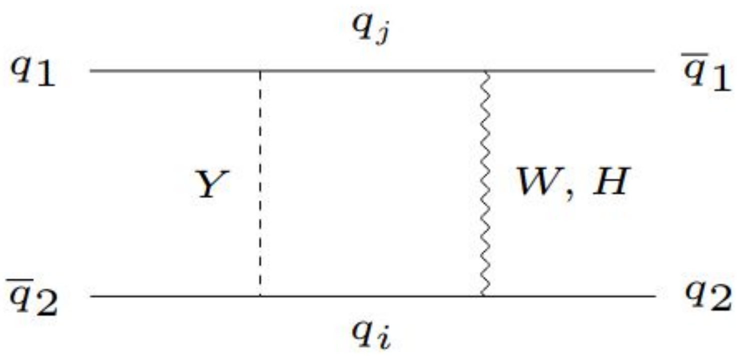


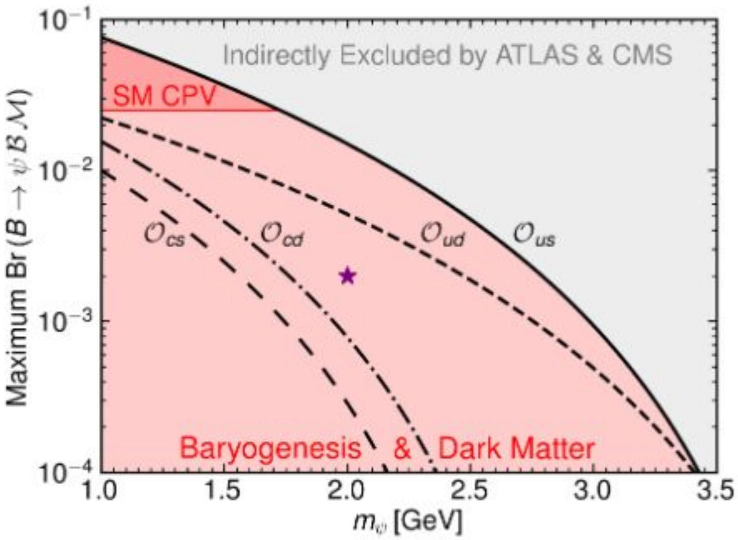


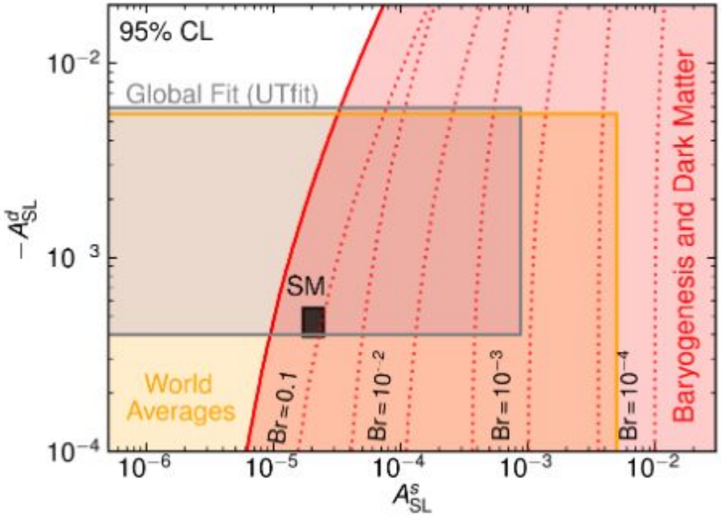
Conclusions

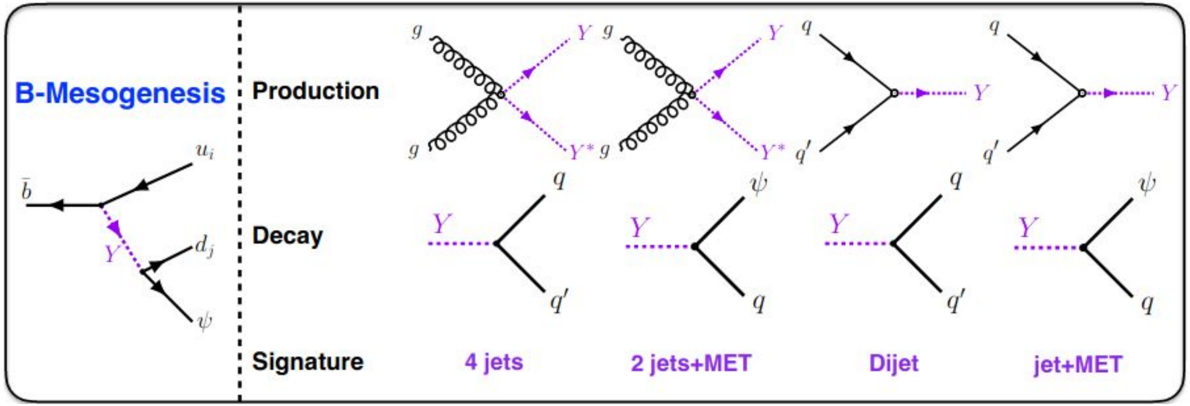
- B-mesogenesis is an elegant solution that solves the baryon asymmetry problem by eliminating the baryon asymmetry
- It can be accurately tested by precise measurements of $B_{s(d)}$ oscillation parameters and searches for b decays to invisible + X
- LHCb can search for those BSM decays with excellent **statistical** accuracy
- Though **systematics** from background modelling **could be a limiting factor**
- Further bkg suppression (as well as a clean signal peak confirmation) can be achieved by identifying the mother of the decaying b-handron (eg , $\Sigma_b^+ \to \Lambda_b \pi^+$)
- LHCb has the **potential** to test the entire parameter space of the model


$q_j\,/\,\psi$
q_1
q_2
Y
Y
$\overline{q}_2$
$\overline{q}_1$
$q_i\,/\,\psi$


q_j
q_1
$\overline{q}_1$
Y
$W,\,H$
$\overline{q}_2$
q_2
q_i


Indirectly Excluded by ATLAS & CMS
SM CPV
Baryogenesis & Dark Matter
Maximum Br (B → ψ B M)
m_ψ [GeV]
10^-1
10^-2
10^-3
10^-4
1.0
1.5
2.0
2.5
3.0
3.5


95% CL
Global Fit (UTfit)
SM
World Averages
Br=0.1
Br=10^-2
Br=10^-3
Br=10^-4
Baryogenesis and Dark Matter
−A^d_SL
A^s_SL
10^-2
10^-3
10^-4
10^-6
10^-5
10^-4
10^-3
10^-2


B-Mesogenesis
Production
Decay
Signature
4 jets
2 jets+MET
Dijet
jet+MET