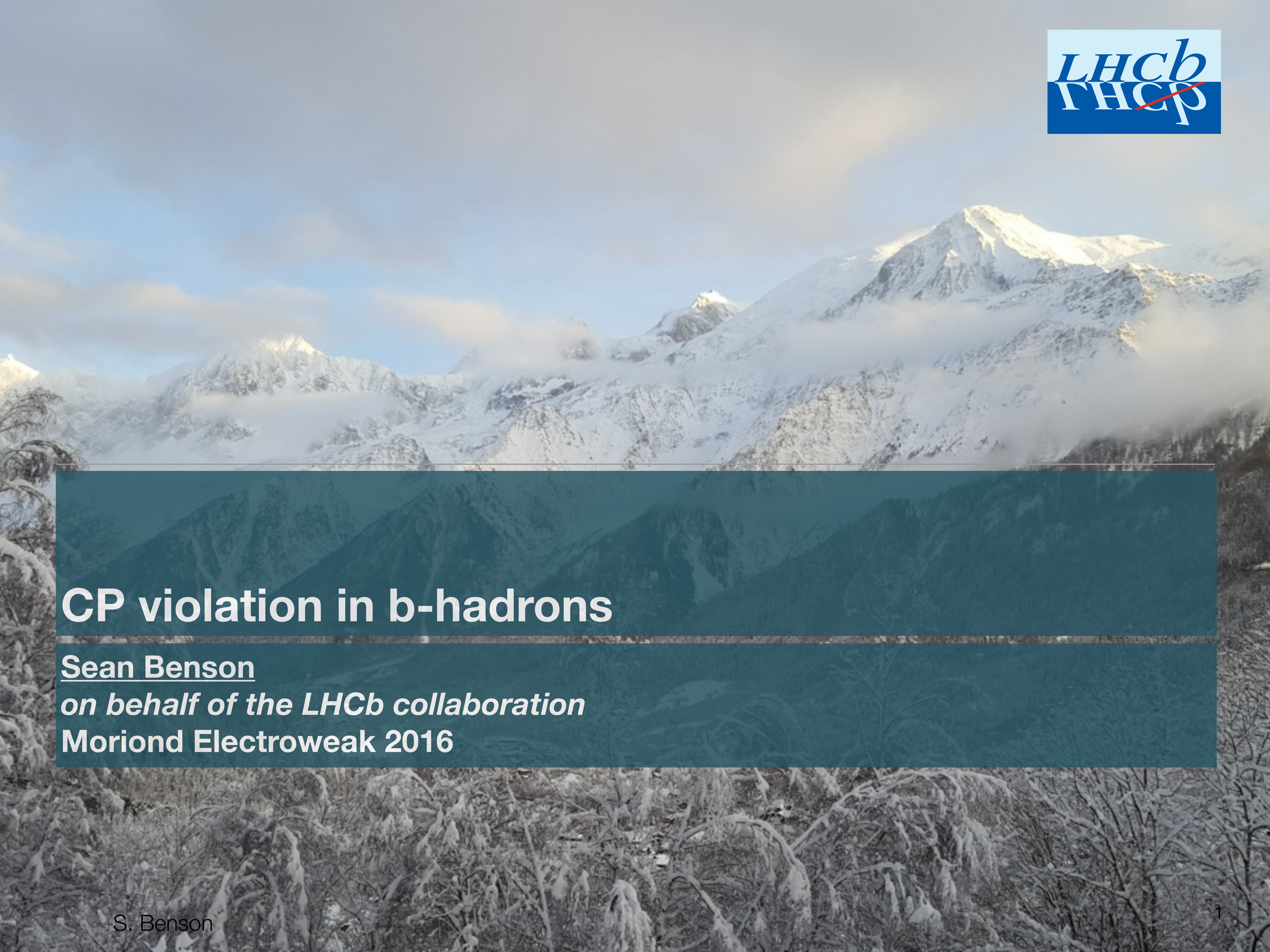


CP violation in b-hadrons

Sean Benson

on behalf of the LHCb collaboration

Moriond Electroweak 2016

Outline

- Overview of CP violation in *b*-decays
  - Measurements of B meson mixing
  - Quantification of penguin pollution

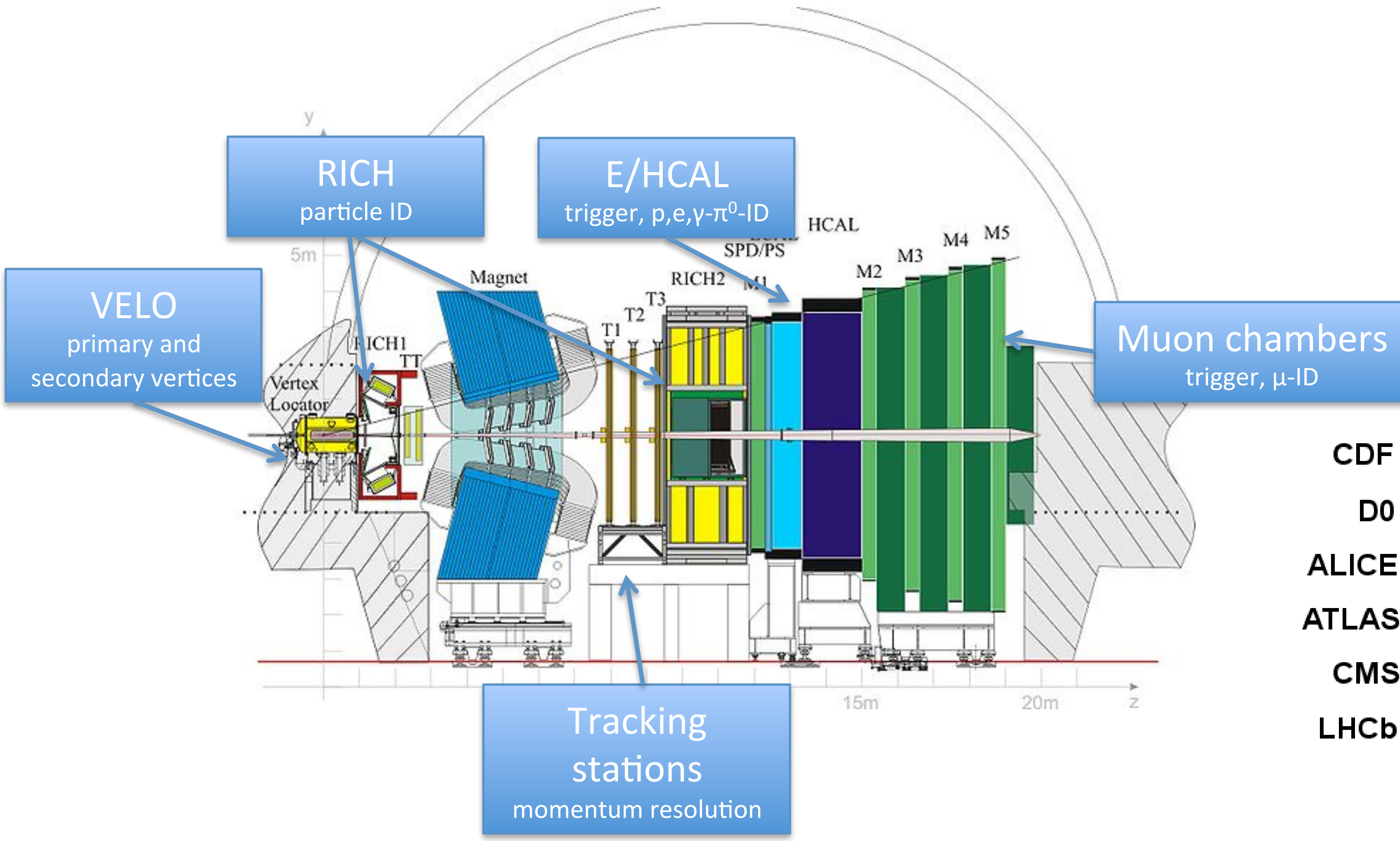
- New physics searches in loop decays

- Searches and CP violation studies in b-baryon decays

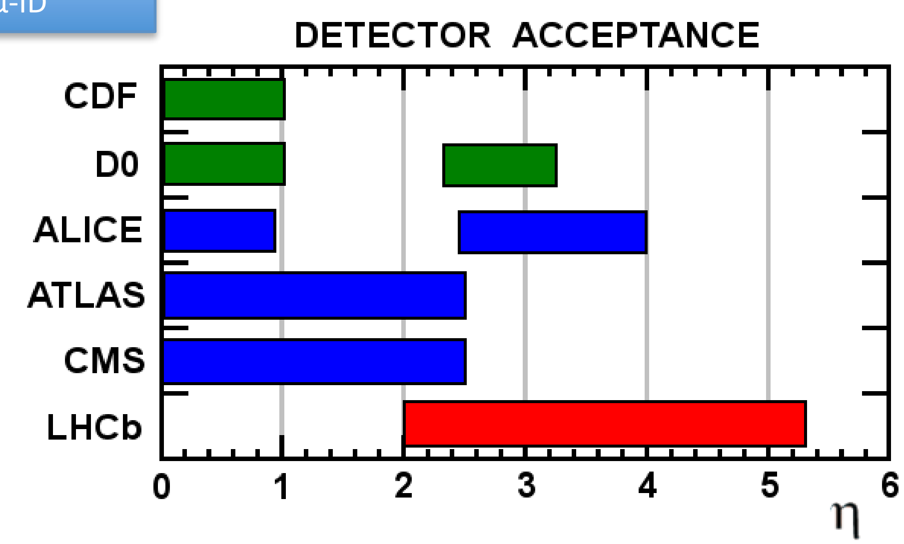
New result $\Lambda_b \to \Lambda\phi$ exclusive search, arXiv:1603.02870

New result $\Lambda_b(\Xi_b) \to \Lambda hh'$ inclusive searches, arXiv:1603.00413 - see dedicated talk by Daniel O'Hanlon on Monday.

LHCb Detector



3fb^{-1} collected in Run 1
0.3fb^{-1} collected in 2015

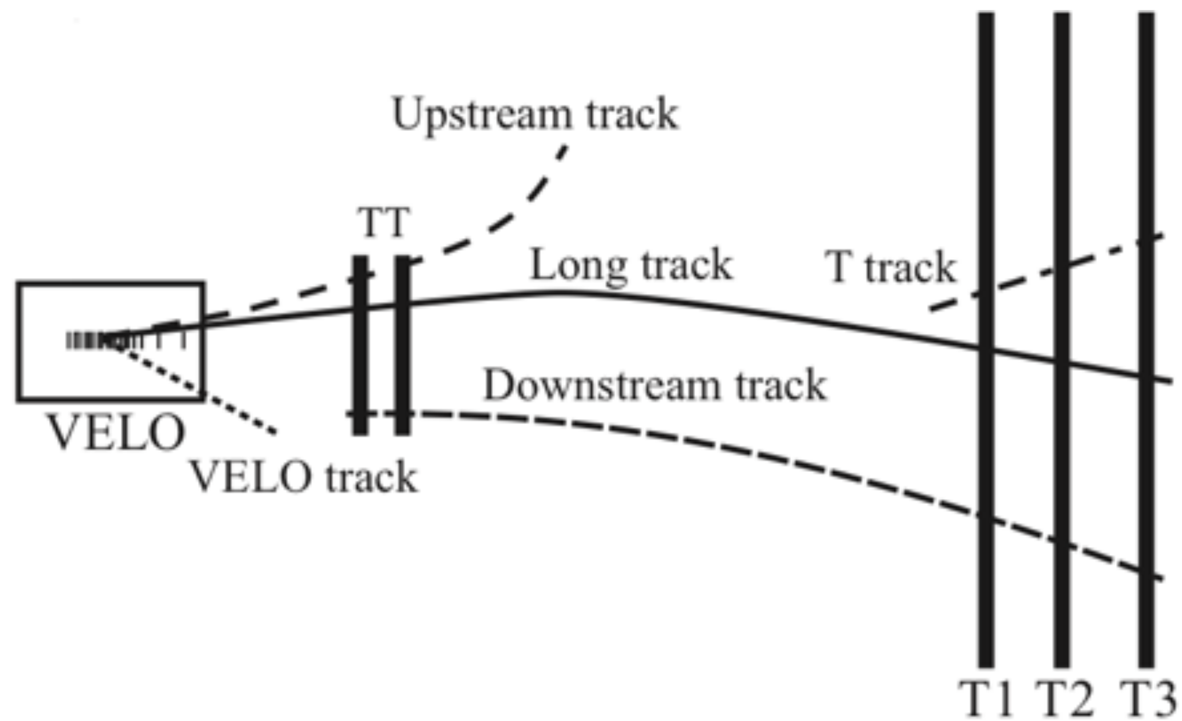


- LHCb is a forward arm spectrometer (pseudo-rapidity range: $2 < \eta < 5$),
- Precise resolutions through vertex locator and tracking stations ($\Delta p/p$~0.4%, σ(IP)~20μm),
- Accurate particle ID provided by RICH detectors,
- High muon identification efficiency from muon stations.

Note on tracks in LHCb

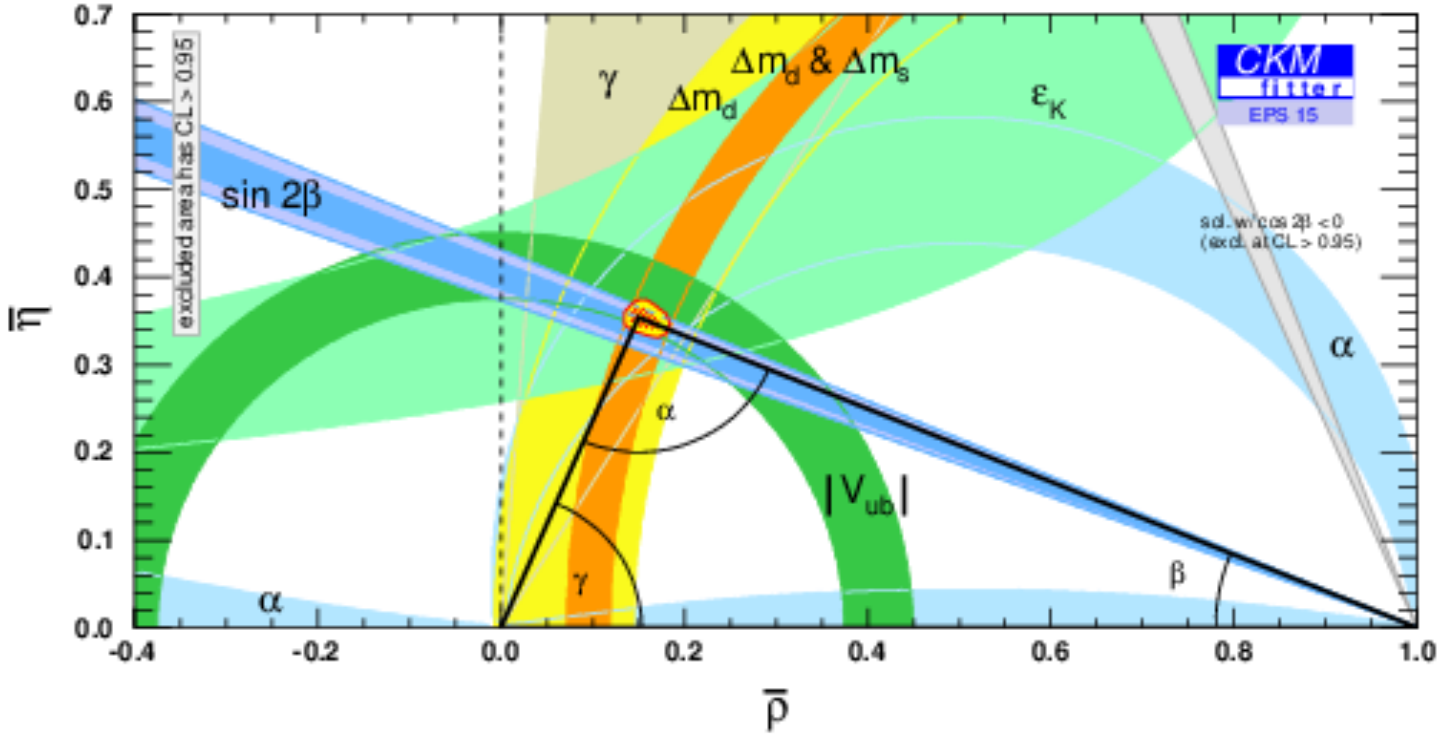
- For long-lived particles such as Λ and K_s hadrons, a large fraction decay outside the vertex detector, and are then reconstructed as downstream.

- Due to different efficiencies and resolutions, so-called long and downstream datasets are treated separately.



Current picture

- Wide array of results from LHCb testing CP violation in b-hadron decays in Run 1:
  - Vast programme to measure the CKM angle γ - see the talk of Malcolm John today.
- So far the SM stands up amazingly (at least in terms of CP violation).
  Picture from CKMfitter:

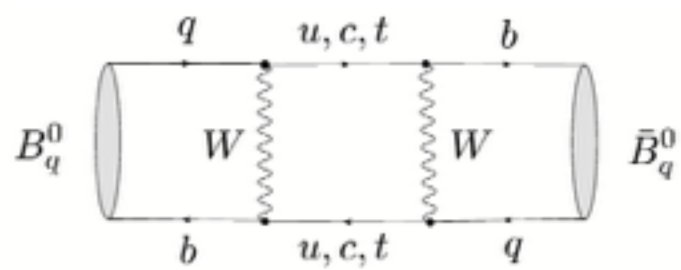


- LHCb is making important contributions, even in places we were not expected to, i.e. $|V_{ub}|$ - see the talk of Jeroen Van Tilburg today.

B_d mixing

- LHCb is able to provide input to the CP-violating phase in B_d mixing, defined as

$$\phi_d \equiv 2\beta = 2\arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$



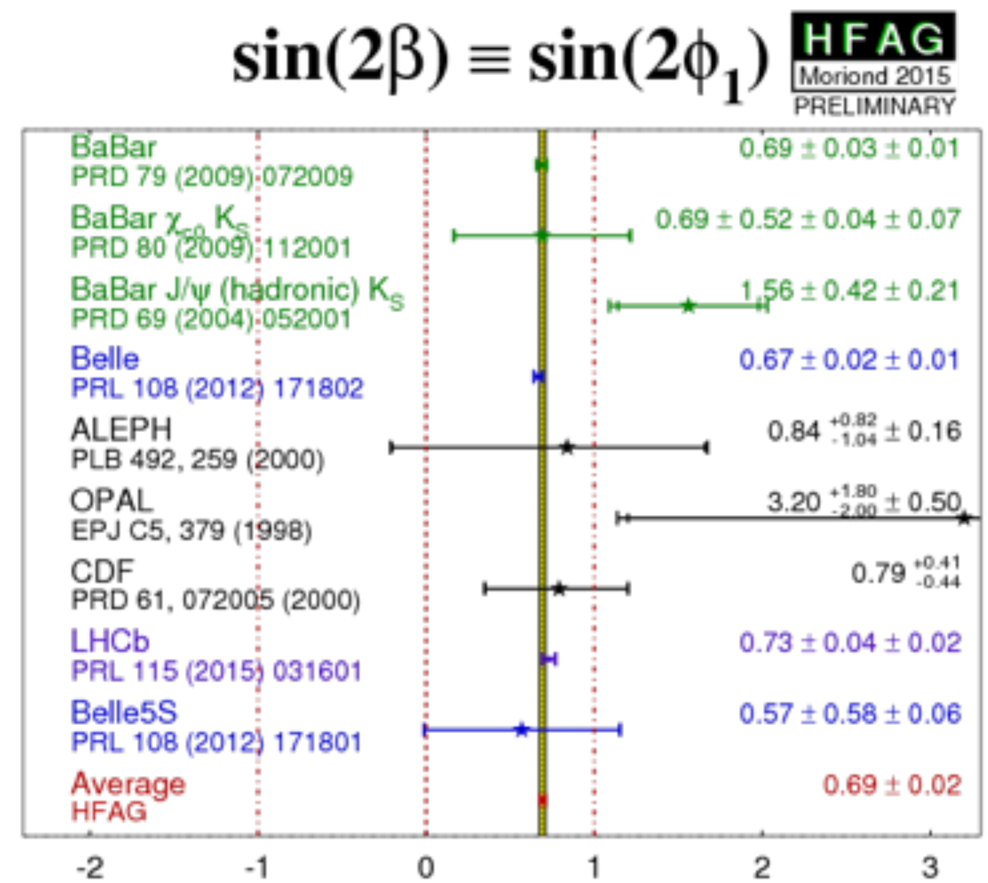
- At LHCb, measured through the time-dependent CP asymmetry in $B_d \to K_S J/\psi$

$$\mathcal{A}(t) \equiv \frac{\Gamma(\overline{B}^0(t) \to J/\psi K_S^0) - \Gamma(B^0(t) \to J/\psi K_S^0)}{\Gamma(\overline{B}^0(t) \to J/\psi K_S^0) + \Gamma(B^0(t) \to J/\psi K_S^0)} = \frac{S\sin(\Delta m\, t) - C\cos(\Delta m\, t)}{\cosh(\frac{\Delta\Gamma t}{2}) + A_{\Delta\Gamma}\sinh(\frac{\Delta\Gamma t}{2})}$$

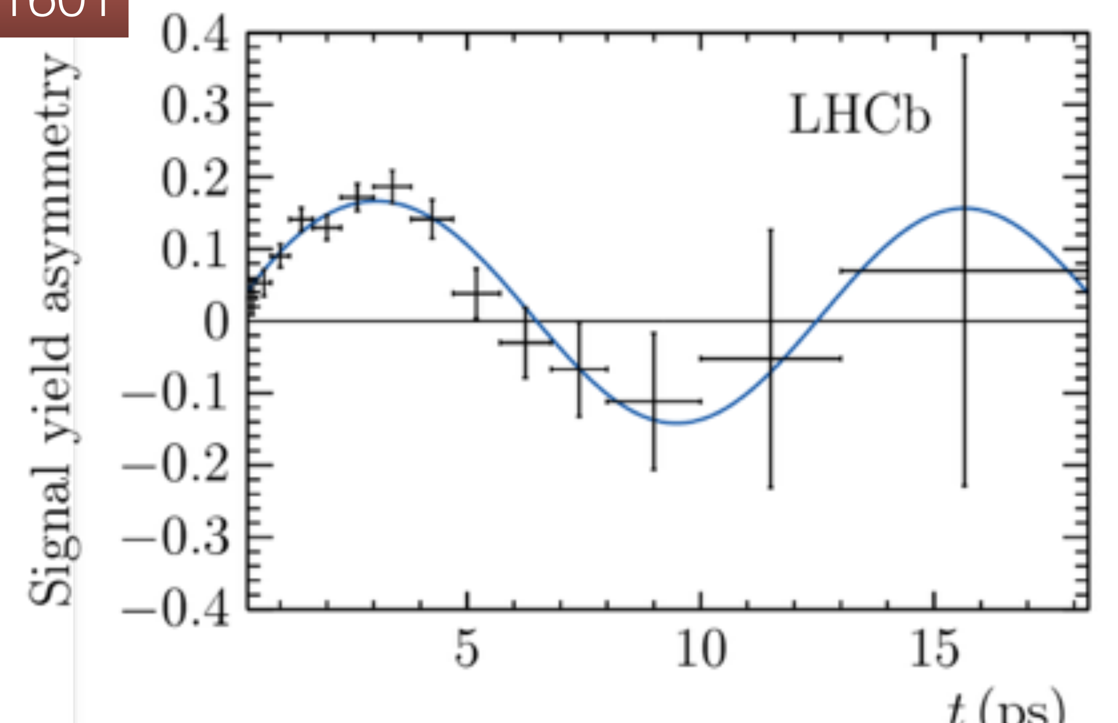
- where

$S = 2\sin\phi_d/(1+|\lambda|^2)$
$C = (1-|\lambda|^2)/(1+|\lambda|^2)$
$A_{\Delta\Gamma} = -2\cos\phi_d/(1+|\lambda|^2)$

- LHCb measurement of $S = \sin 2\beta = 0.731 \pm 0.035 \pm 0.020$ is approaching the precision of the B-factories

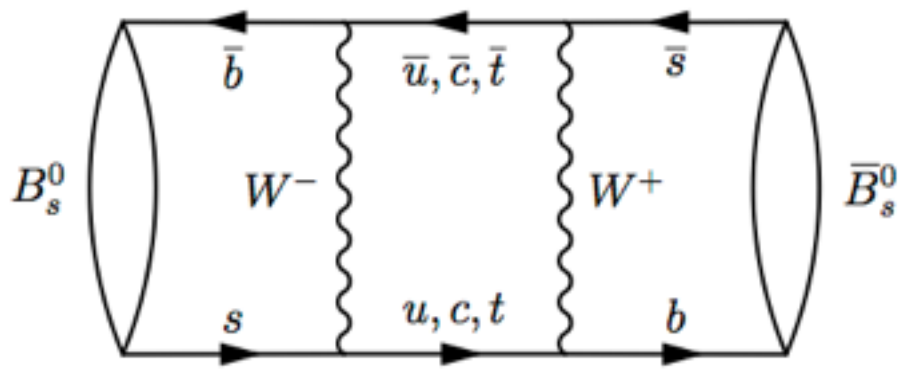


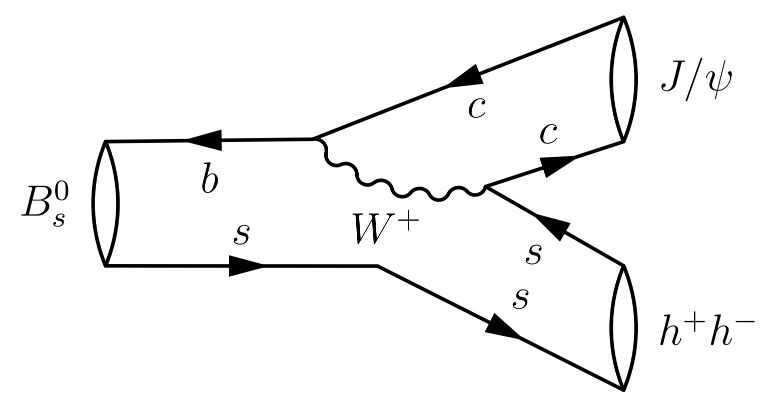
LHCb: PRL 115 (2015) 031601



B_s mixing

- An important measurement for LHCb is that of CP violation in B_s mixing, tested with tree-dominated $b \to c\bar{c}s$ decays.

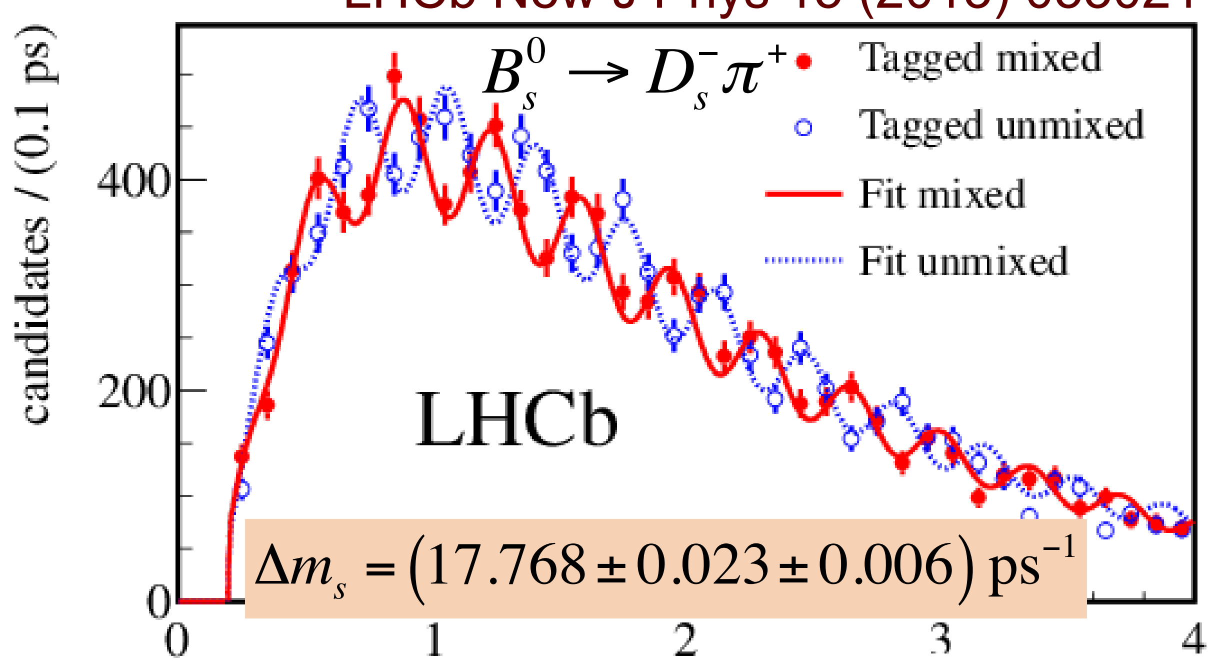




$$\phi_s \equiv -2\beta_s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$$

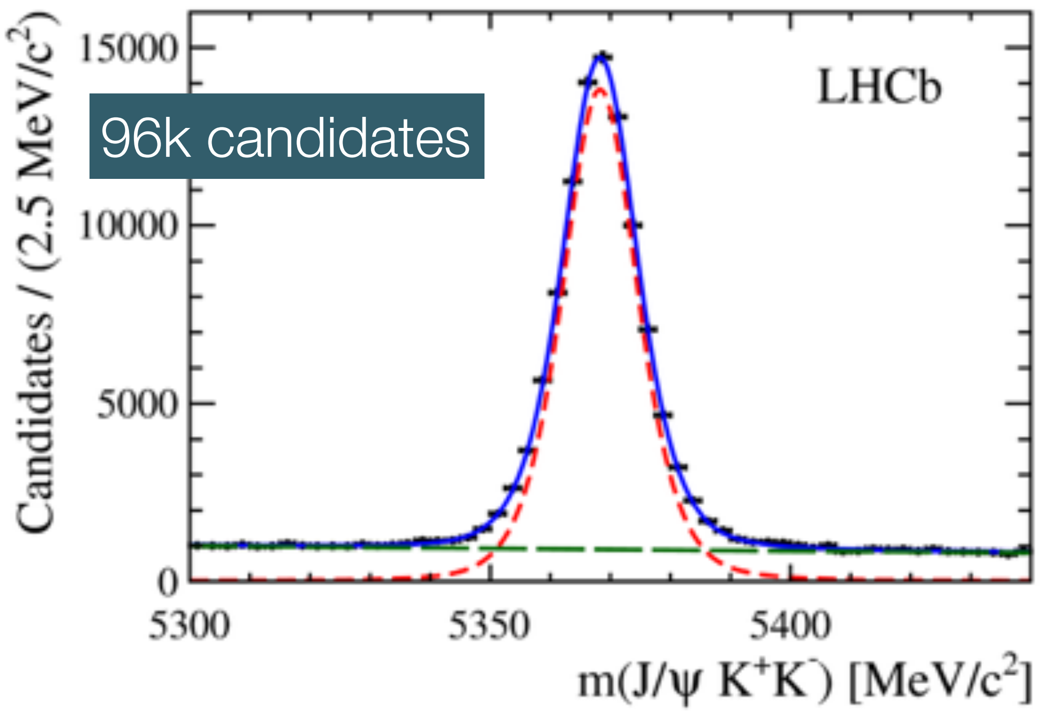
- Experimentally very complex due to mixture of CP eigenstates in the $B_s \to J/\psi KK$ transition
- CP eigenstates disentangled with an angular analysis
- Require excellent knowledge of the initial B meson flavour and B decay time resolution.

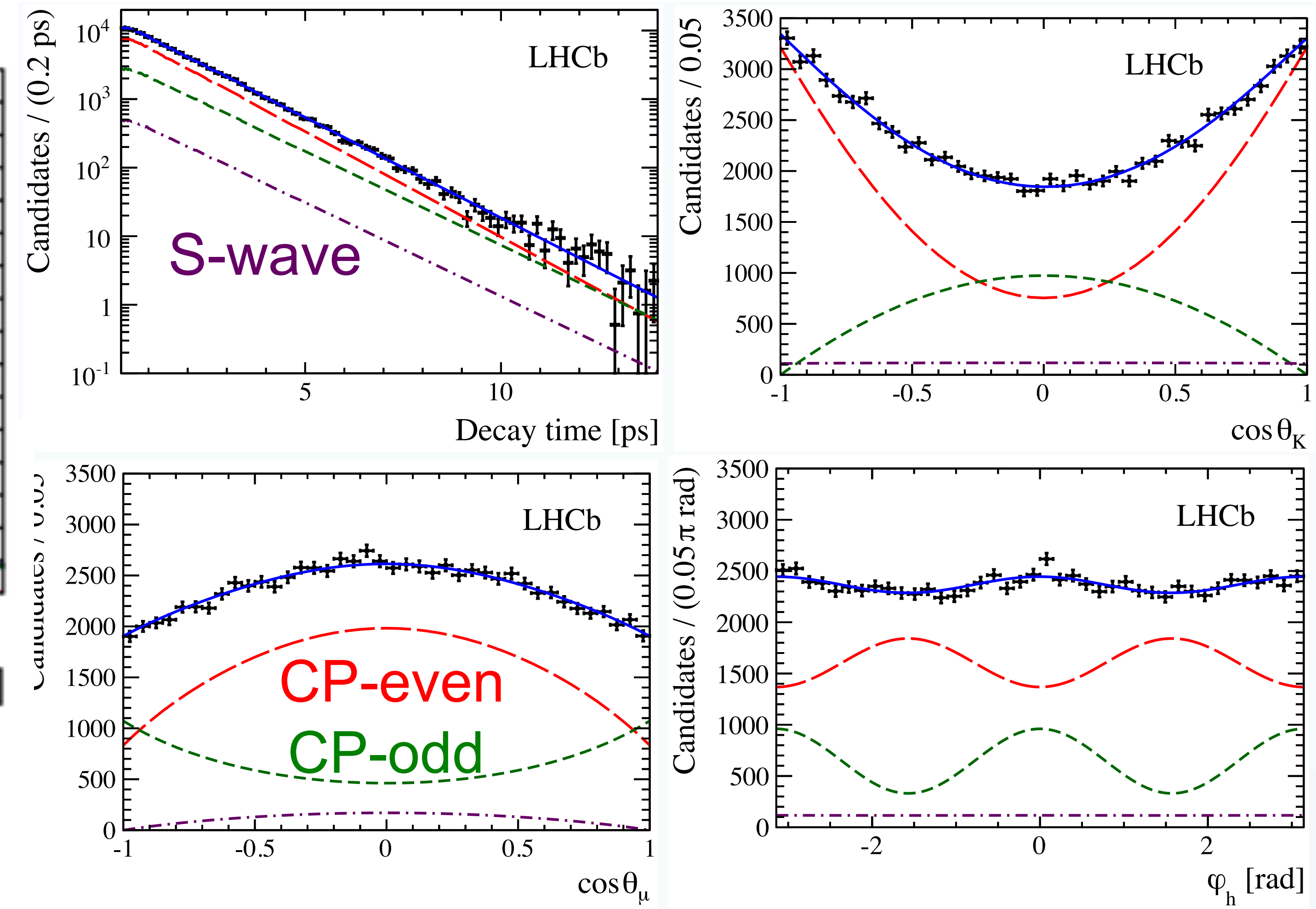
LHCb New J Phys 15 (2013) 053021

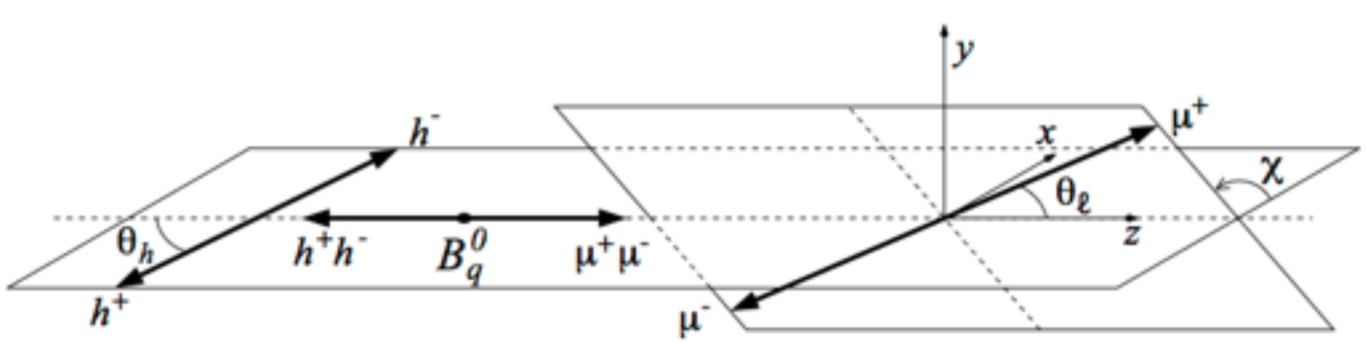


B_s mixing

PRL 114 (2015) 041801







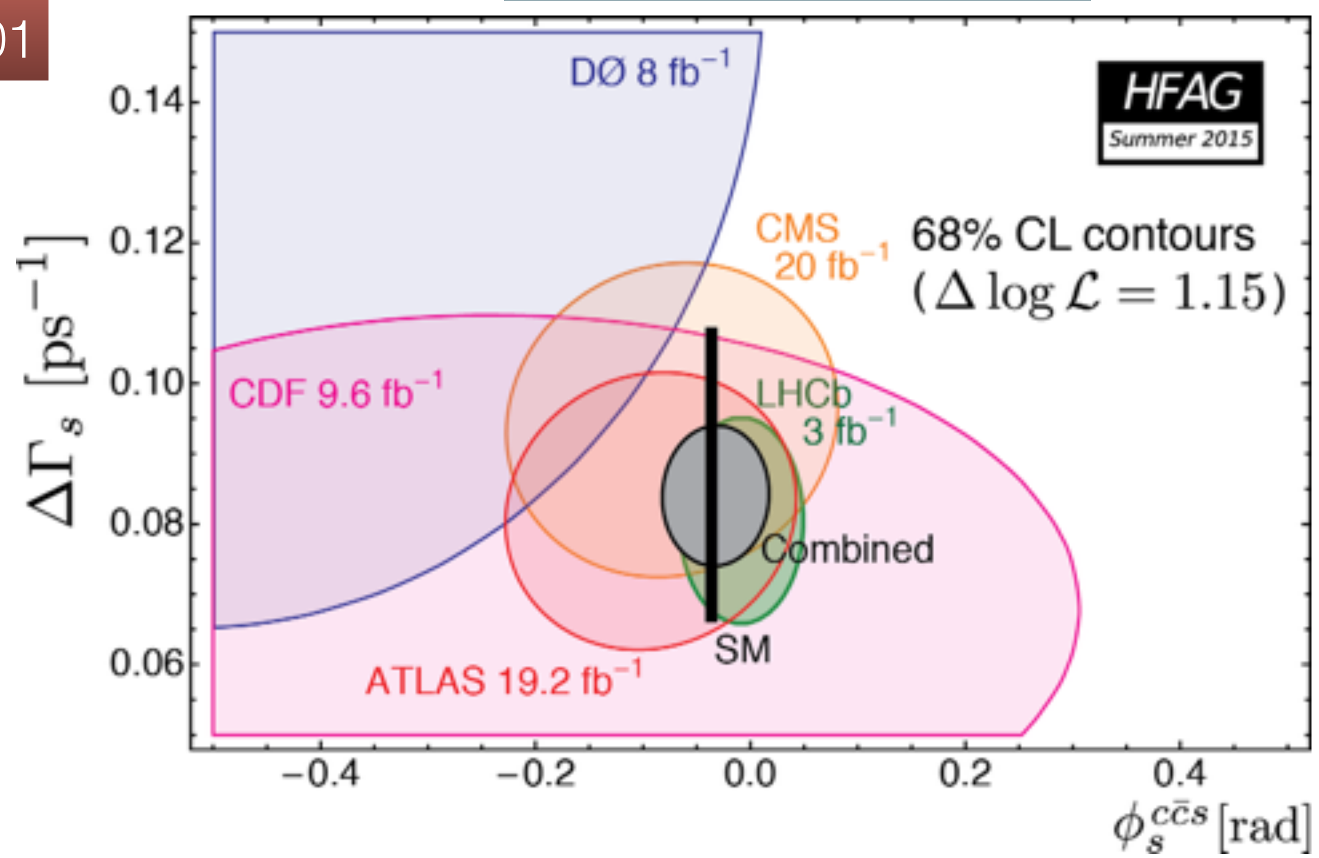
Result combined with 27k $B_s \to J/\psi\pi\pi$ candidates

B_s mixing

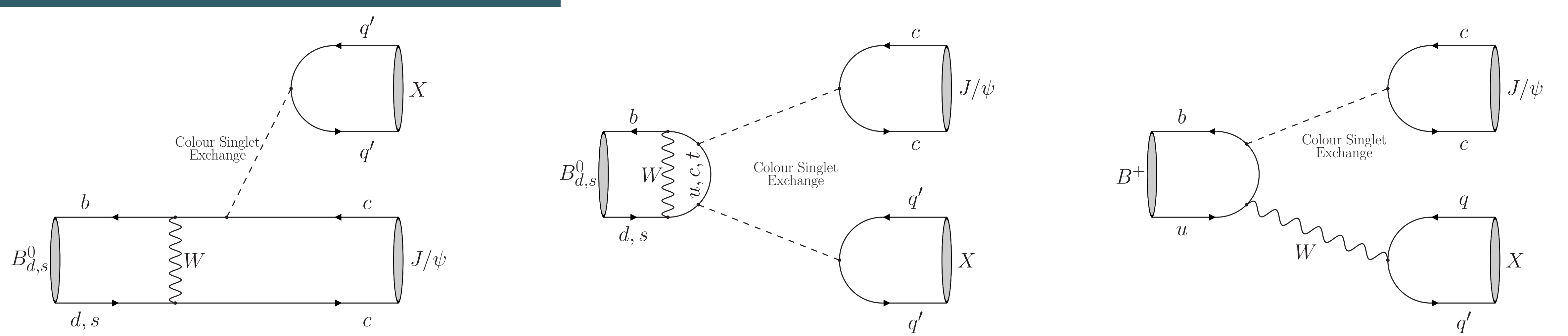
- LHCb measurement of -10±39 mrad dominates the global fit PRL 114 (2015) 041801
- Constraining power of the measurement will increase as LHCb accumulates more data.
- Attention turns more to control of penguin pollution…

$$\phi_{s,i} = -2\beta_s + \phi_s^{\text{BSM}} + \Delta\phi_{s,i}^{J/\psi\,\phi}(a'_i, \theta'_i)$$

Global fit: -34±33 mrad



De Bruyn & Fleischer, arXiv:1412.6834



Penguin pollution

JHEP 11 (2015) 082

- LHCb can measure $\Delta\phi_{\text{penguin}}$ in decays that do not have the penguin amplitude suppressed.

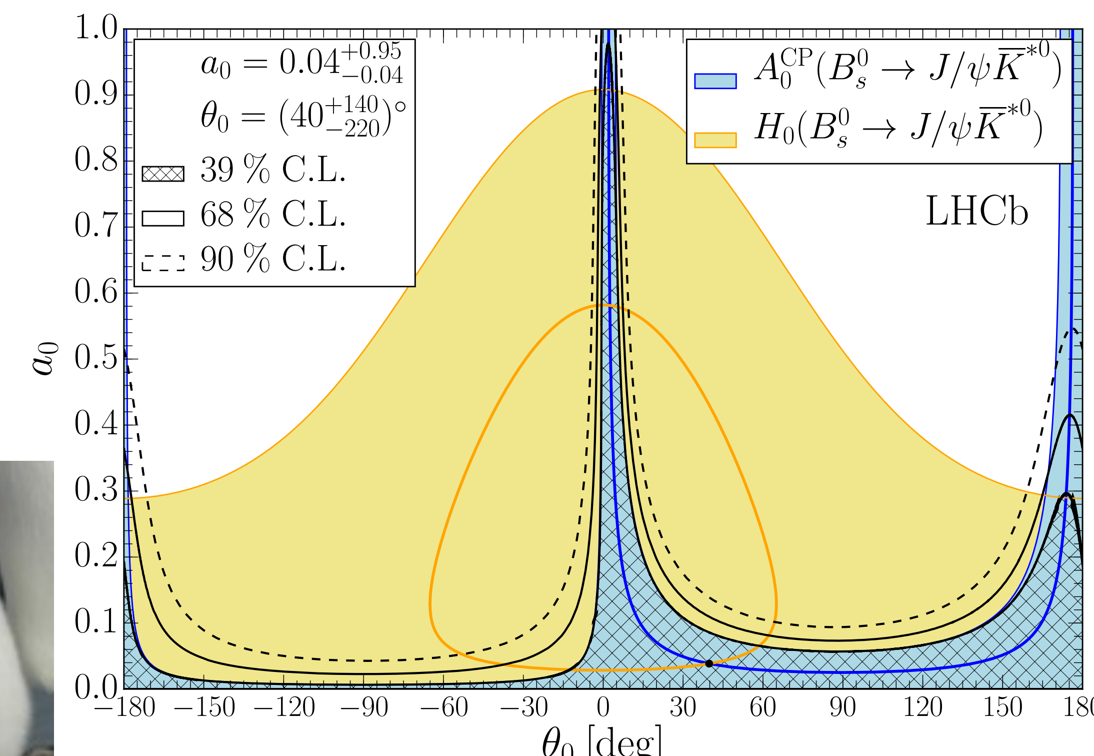
$$A\left(B_s^0 \to (J/\psi\,\overline{K}^{*0})_i\right) = -\lambda\mathcal{A}_i\left[1 - a_i e^{\mathrm{i}\theta_i} e^{\mathrm{i}\gamma}\right]$$

$$A\left(B_s^0 \to (J/\psi\,\phi)_i\right) = \left(1 - \frac{\lambda^2}{2}\right)\mathcal{A}_i'\left[1 + \epsilon a_i' e^{\mathrm{i}\theta_i'} e^{\mathrm{i}\gamma}\right]$$

Can parameterise penguin and tree contributions to each polarisation amplitude

- Assuming SU(3) symmetry, $a_i=a_i'$ and $\theta_i=\theta_i'$
- a and θ can be determined from the data with a modified least squares fit to CP asymmetries and branching fraction information.
- In combination with an equivalent study using $B_d \to J/\psi\rho$ decays (Phys.Lett. B742 (2015) 38-49), penguin pollution can be evaluated as:

Detailed relations between $\{a,\theta\} \Leftrightarrow \{A^{CP},H\}$ given in the backup

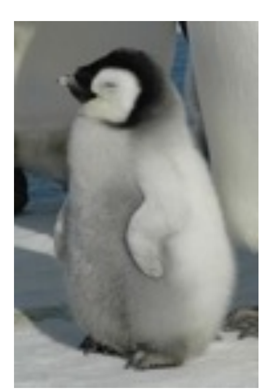


$$\Delta\phi_{s,0}^{J/\psi\,\phi} = 0.000^{+0.009}_{-0.011}\,(\text{stat})\ {}^{+0.004}_{-0.009}\,(\text{syst})\,\text{rad}$$

$$\Delta\phi_{s,\parallel}^{J/\psi\,\phi} = 0.001^{+0.010}_{-0.014}\,(\text{stat}) \pm 0.008\,(\text{syst})\,\text{rad}$$

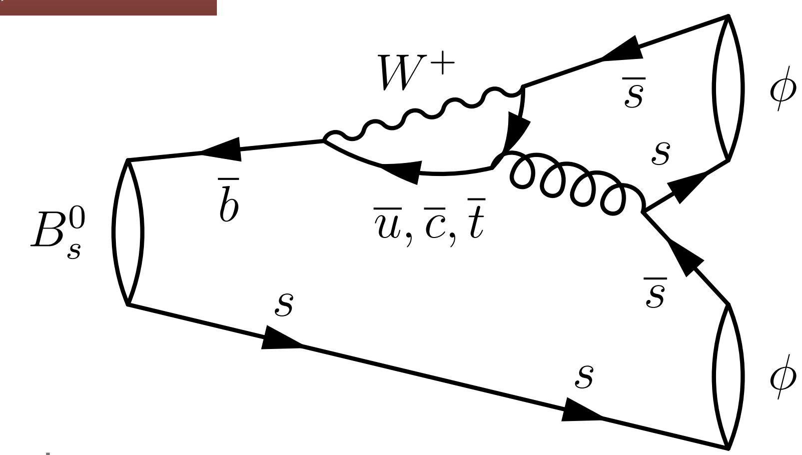
$$\Delta\phi_{s,\perp}^{J/\psi\,\phi} = 0.003^{+0.010}_{-0.014}\,(\text{stat}) \pm 0.008\,(\text{syst})\,\text{rad}$$

Conclusion: penguin contamination is small



Penguin measurements - $B_s \to \phi\phi$

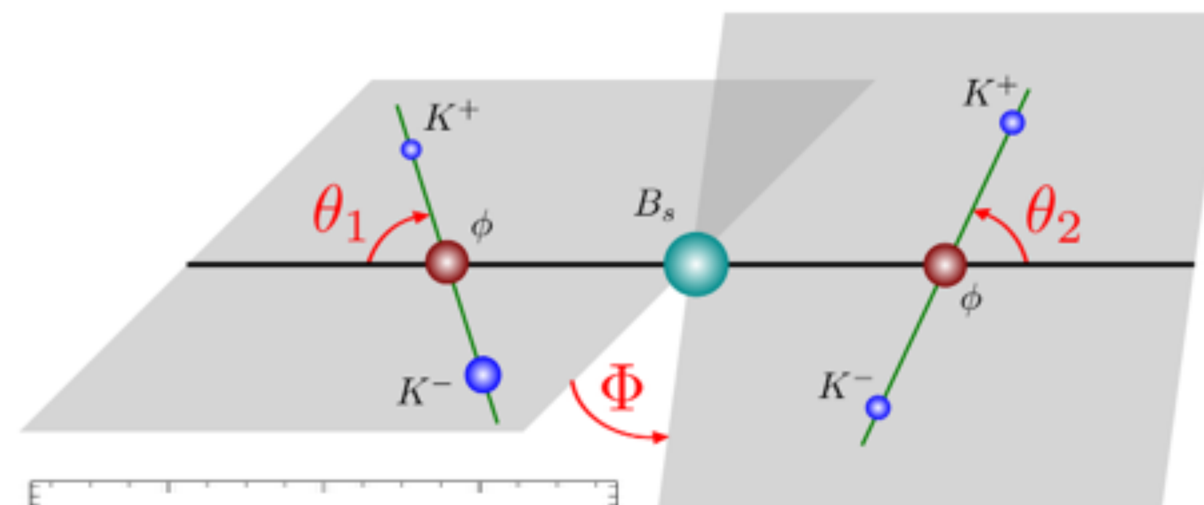
Phys.Rev. D90 (2014) 5, 052011

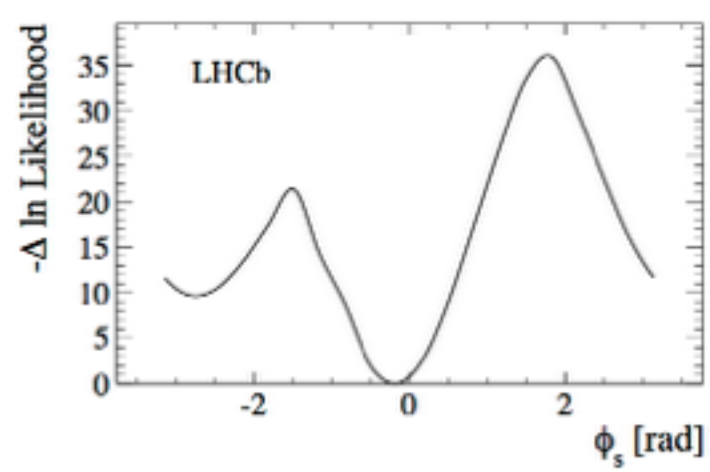


- Not all penguins are bad news…
- Penguins are also important in searches for new physics (hep-ph/0007328, arXiv:1212.6486, hep-ph/0510245, arXiv:0811.2957)
- SM predictions of the CP violating phase in b->ss̄s penguin decays (arXiv:0810.0249, arXiv:0910.5237) predict values close to 0.
- Amplitude analysis to disentangle the CP components of the $B_s \to \phi\phi$ decay.

  .
- 4000 candidates from 3fb^{-1} of Run 1 data.
- LHCb measures the CP-violating phase to be (arXiv:1407.2222)

  -0.17±0.15±0.03 rad.



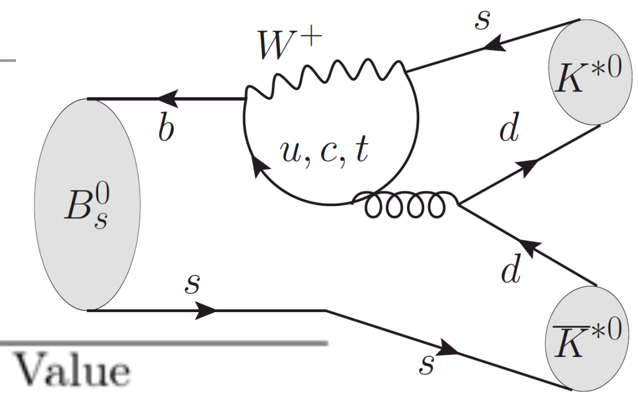


Low systematic contributions,
very interesting with Run 2 dataset sizes

Penguin measurements - $B_s \to K^* K^*$

JHEP 07 (2015) 166

- Analysis a pure $b \to s\bar{d}d$ transition.
- Mixture of CP eigenstates,
  so requires an angular amplitude analysis

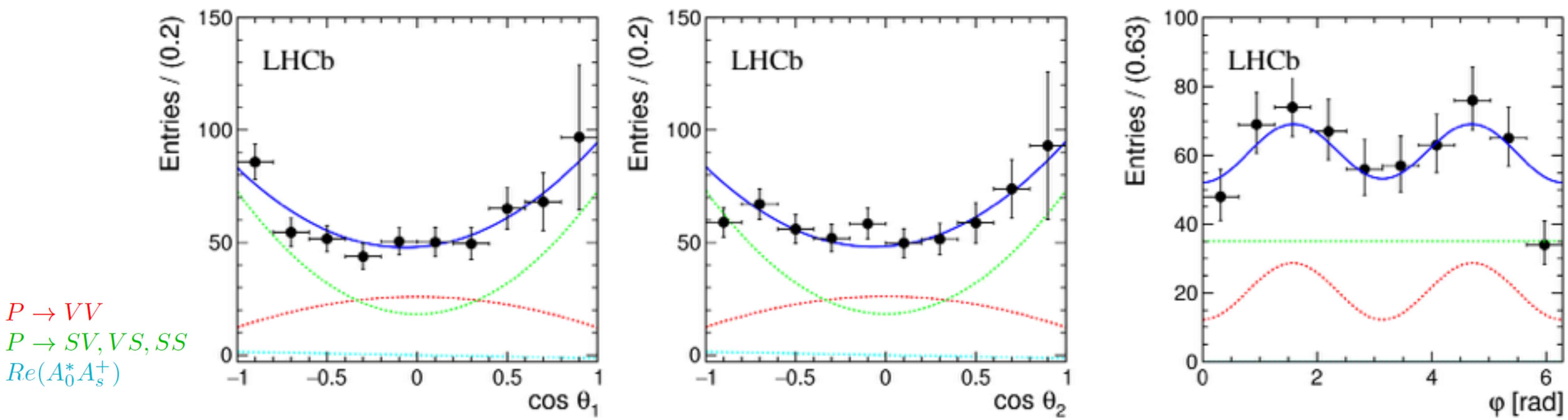


Low value of f_L confirmed

Large S-wave

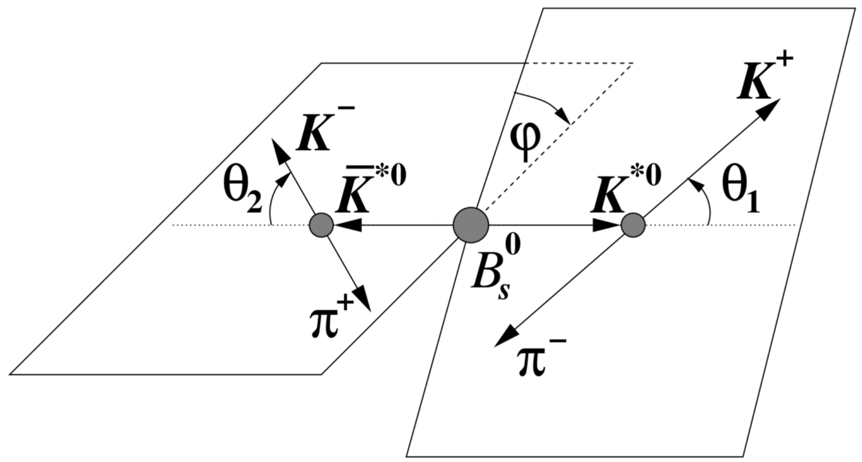
Parameter	Value
f_L	$0.201 \pm 0.057 \pm 0.040$
$f_{\parallel}$	$0.215 \pm 0.046 \pm 0.015$
$\lvert A_s^+\rvert^2$	$0.114 \pm 0.037 \pm 0.023$
$\lvert A_s^-\rvert^2$	$0.485 \pm 0.051 \pm 0.019$
$\lvert A_{ss}\rvert^2$	$0.066 \pm 0.022 \pm 0.007$
$\delta_{\parallel}$	$5.31 \pm 0.24 \pm 0.14$
$\delta_{\perp} - \delta_s^+$	$1.95 \pm 0.21 \pm 0.04$
δ_s^-	$1.79 \pm 0.19 \pm 0.19$
δ_{ss}	$1.06 \pm 0.27 \pm 0.23$

$1\,\text{fb}^{-1}$ of Run 1 data yields ~700 events



Penguin measurements - $B_s \to K^*K^*$

JHEP 07 (2015) 166



Triple products measured through asymmetries of angular observables - Gronau & Rosner arXiv:1506.01346

$$A_T^3 \equiv \frac{\Gamma((\cos\theta_1+\cos\theta_2)\sin\varphi>0)-\Gamma((\cos\theta_1+\cos\theta_2)\sin\varphi<0)}{\Gamma((\cos\theta_1+\cos\theta_2)\sin\varphi>0)+\Gamma((\cos\theta_1+\cos\theta_2)\sin\varphi<0)}$$
$$= \frac{32}{5\pi\sqrt{3}}\frac{1}{\mathcal{D}}\int \mathcal{I}m\left(\left(\mathcal{A}_\perp\mathcal{A}_s^{-*}-\bar{\mathcal{A}}_\perp\bar{\mathcal{A}}_s^{-*}\right)\mathcal{M}_1(m)\mathcal{M}_0^*(m)\right)\mathrm{d}m$$

Asymmetry	Value
A_T^1	$0.003 \pm 0.041 \pm 0.009$
A_T^2	$0.009 \pm 0.041 \pm 0.009$
A_T^3	$0.019 \pm 0.041 \pm 0.008$
A_T^4	$-0.040 \pm 0.041 \pm 0.008$
A_D^1	$-0.061 \pm 0.041 \pm 0.012$
A_D^2	$0.081 \pm 0.041 \pm 0.008$
A_D^3	$-0.079 \pm 0.041 \pm 0.023$
A_D^4	$-0.081 \pm 0.041 \pm 0.010$

4 CP-even polarisations give rise to 4 triple product asymmetries and 4 direct asymmetries

$$\mathcal{A}_T^i \propto Im(A_f^* A_\perp - \bar{A}_f^* \bar{A}_\perp)$$
$$\mathcal{A}_D^i \propto Re(A_f^* A_s^+ - \bar{A}_f^* \bar{A}_s^+)$$

CP-even: $f = 0, \|, s^-, ss$
CP-odd: $\perp, s^+$

Observation of the $\Lambda_b \to \Lambda\phi$ decay, arXiv:1603.02870

New result

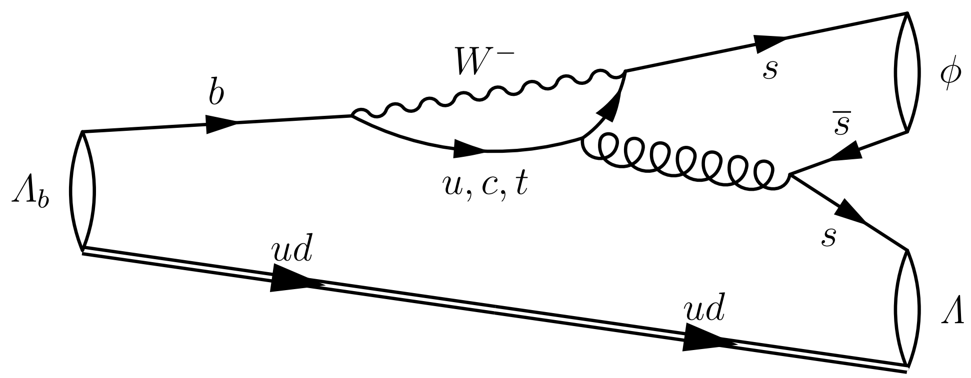
- Submitted to Phys. Lett. B.
- Based on 3fb^{-1} of Run 1 data.

- Baryonic version of the $B_s \to \phi\phi$ decay.

- $B_d \to K_s\phi$ control mode used for BF measurement

- As for B decays, polarisation structure of $\Lambda_b \to \Lambda V$ decays gives rise to *T*-odd observables.
  - Allow access to CP violation without the use of a control mode.

- Measurements probe the decay directly without the presence of mixing.

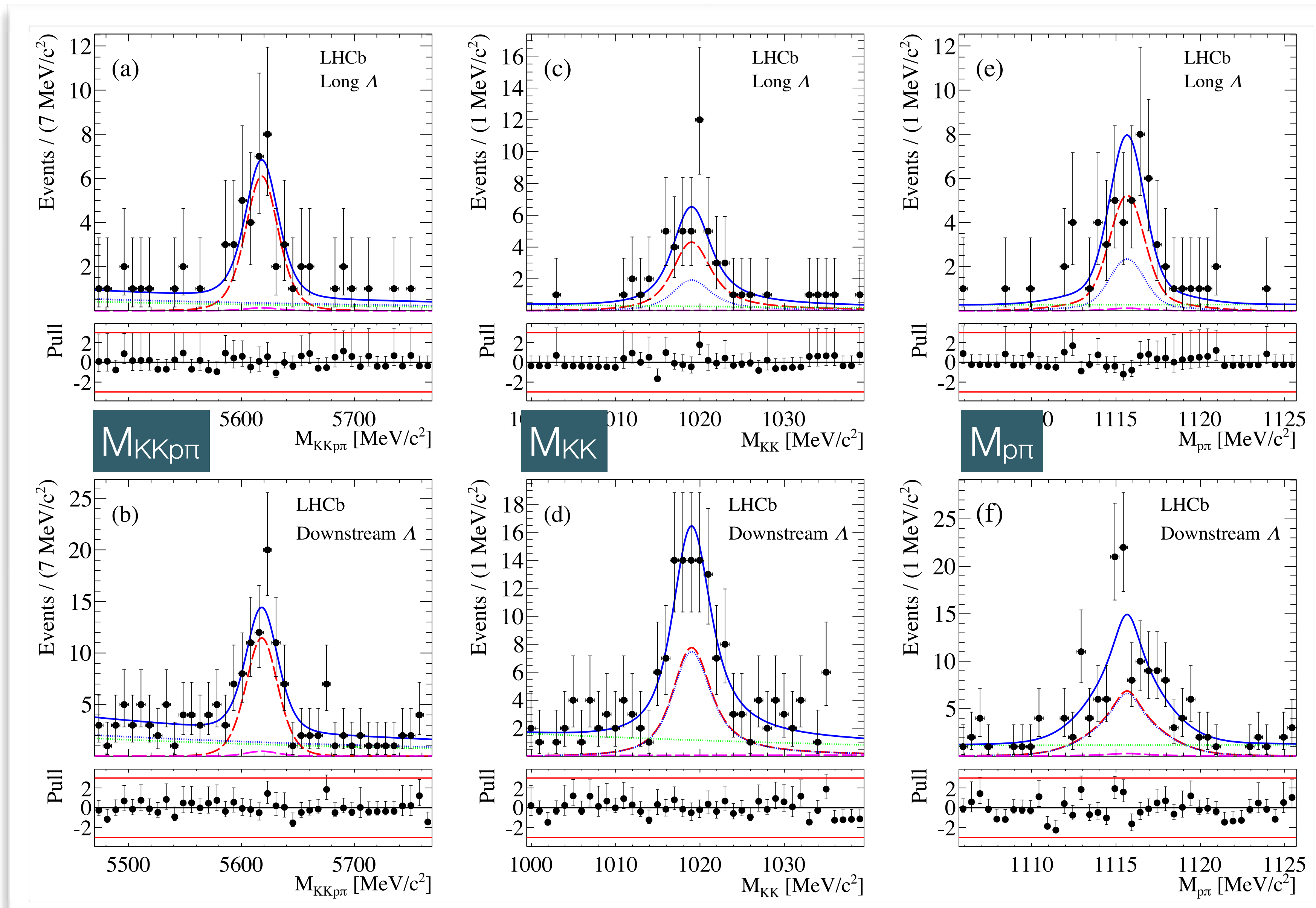


Observation of the $\Lambda_b \to \Lambda\phi$ decay, arXiv:1603.02870

New result

- 3D fit performed in the KKpπ, KK, pπ dimensions.
- Decay observed with 6.5σ statistical significance (5.9σ including systematic uncertainties).

89±13 combined signal yield



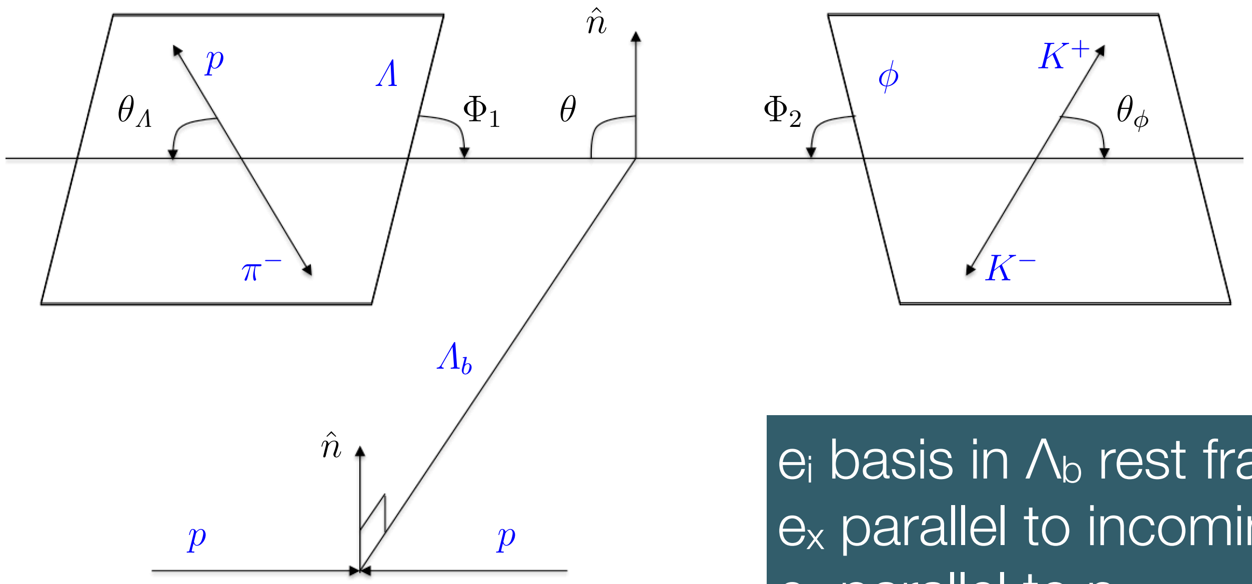
signal
combinatorial
$\Lambda_b \to \Lambda KK$ non-res
true $\Lambda + \phi$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\phi)/10^{-6} =$$
$$5.18 \pm 1.04\,(\text{stat}) \pm 0.35\,(\text{syst})\,{}^{+0.50}_{-0.43}\,(\mathcal{B}(B^0 \to K_S^0\phi)) \pm 0.44\,(f_d/f_{\Lambda_b^0})$$

Observation of the $\Lambda_b \to \Lambda\phi$ decay, arXiv:1603.02870

New result

- With a large enough dataset, a full angular analysis may be performed as has been done for $\Lambda_b \to \Lambda J/\psi$ - arXiv:1302.5578



e_i basis in Λ_b rest frame
e_x parallel to incoming proton
e_z parallel to n

- *T*-odd observables are accessible without a full angular analysis.
- Use convention of Leitner and Ajaltouni - hep-ph/0610189

$$\cos\Phi_{n_i} = \vec{e}_Y \cdot \vec{u}_i$$
$$\sin\Phi_{n_i} = \vec{e}_Z \cdot (\vec{e}_Y \times \vec{u}_i)$$

$$\vec{u}_i = \frac{\vec{e}_Z \times \hat{n}_i}{|\vec{e}_Z \times \hat{n}_i|}$$

$$A^c_\Lambda = -0.22 \pm 0.12\,(\text{stat}) \pm 0.06\,(\text{syst})$$
$$A^s_\Lambda = 0.13 \pm 0.12\,(\text{stat}) \pm 0.05\,(\text{syst})$$
$$A^c_\phi = -0.01 \pm 0.12\,(\text{stat}) \pm 0.03\,(\text{syst})$$
$$A^s_\phi = -0.07 \pm 0.12\,(\text{stat}) \pm 0.01\,(\text{syst})$$

Asymmetries consistent with zero

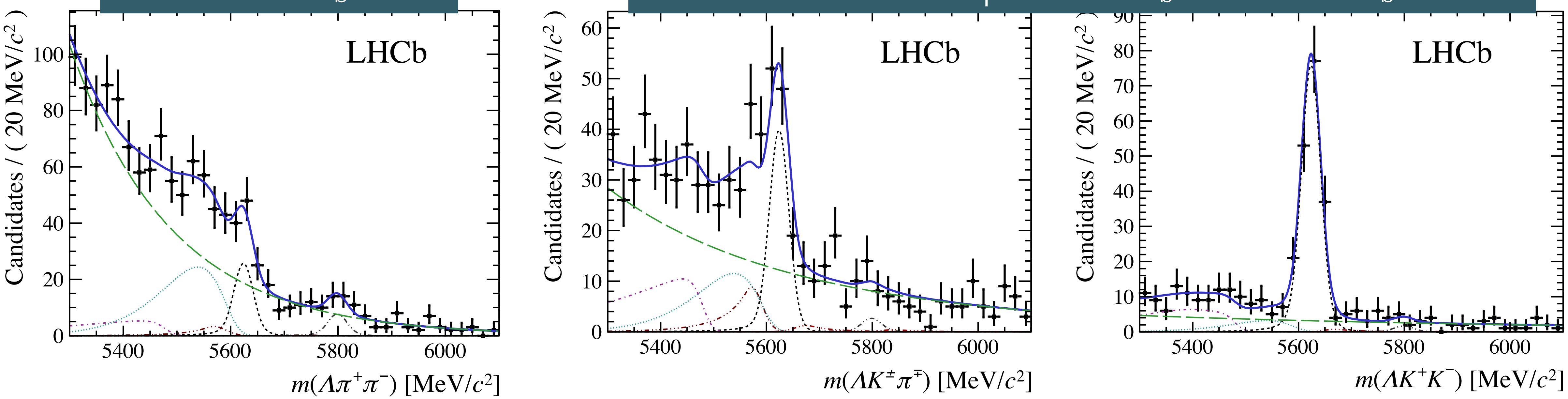
$\Lambda_b(\Xi_b) \to \Lambda hh'$ inclusive searches, arXiv:1603.00413

New result

See talk of Daniel O'Hanlon tomorrow in YSF

Evidence for $\Lambda_b \to \Lambda\pi\pi$

First observations reported of $\Lambda_b \to \Lambda KK$ and $\Lambda_b \to \Lambda K\pi$



Plots show long and downstream combined

Measurements of branching fractions and CP asymmetries relative to the $\Lambda_b \to \Lambda_c\pi$ control mode

$$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+\pi^-) = -0.53 \pm 0.23 \pm 0.11$$
$$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+K^-) = -0.28 \pm 0.10 \pm 0.07$$

CP asymmetries measured for observed decays, which are interesting though consistent with zero

Summary

- Wide programme at LHCb for tests of the SM.
- Precision is everything:
  - SM is holding up pretty well at current levels of precision.

    2β - PRL 115 (2015) 031601

    $2\beta_s$ - PRL 114 (2015) 041801

  - Experimental measurements used to determine affect of penguin pollution on CP violation measurements.

    $B_s \to J/\psi K^*$ - JHEP 11 (2015) 082

  - Penguin modes themselves are important searches for physics beyond the SM.

    $b \to sd\bar{d}$ - JHEP 07 (2015) 166

    $b \to s\bar{s}s$ - Phys.Rev. D90 (2014) 5, 052011

- First exploratory studies undertaken of new baryonic modes:

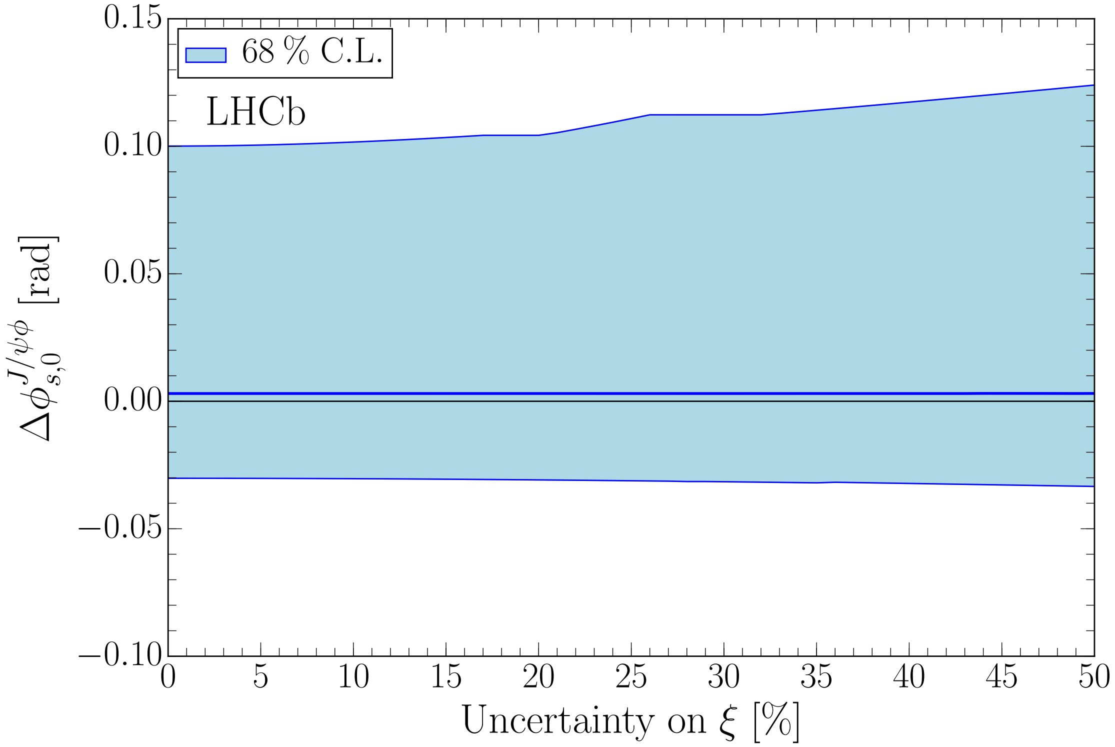
  $\Lambda_b \to \Lambda\phi$ - arXiv:1603.02870

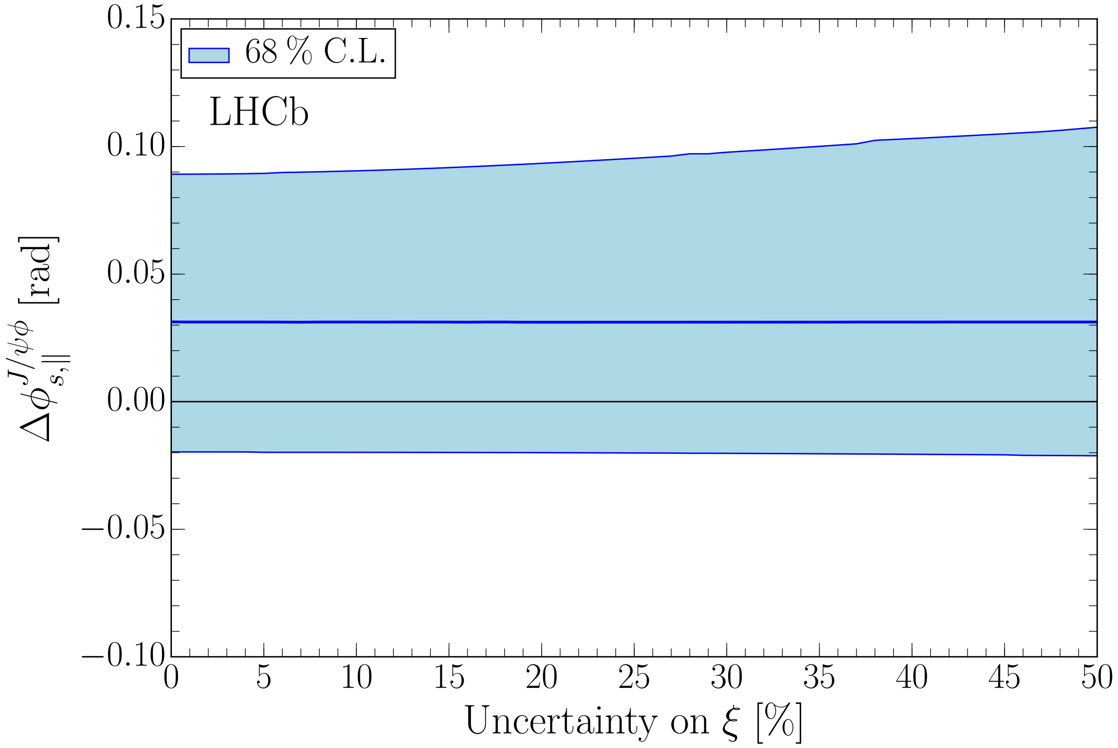
  $\Lambda_b \to \Lambda hh$ - arXiv:1603.00413

Run 2 of the LHC will mean the SM will be tested in flavour observables to new levels. Stay tuned…

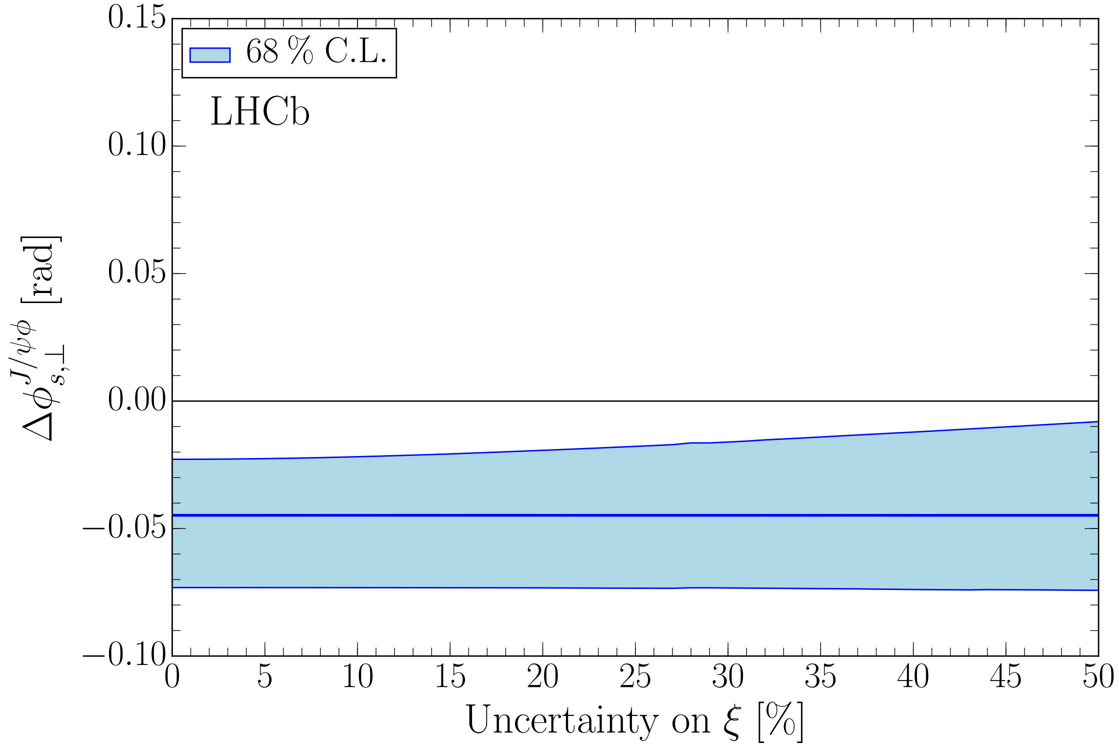
Backup

Backup: SU(3) breaking





$$a_i' = \xi \times a_i \;, \qquad \theta_i' = \theta_i + \delta$$



Backup: Penguin pollution

$$\tan(\Delta\phi_{s,i}^{J/\psi\,\phi}) = \frac{2\epsilon a_i' \cos\theta_i' \sin\gamma + \epsilon^2 a_i'^2 \sin(2\gamma)}{1 + 2\epsilon a_i' \cos\theta_i' \cos\gamma + \epsilon^2 a_i'^2 \cos(2\gamma)}$$

$$A_i^{CP} = -\frac{2a_i \sin\theta_i \sin\gamma}{1 - 2a_i \cos\theta_i \cos\gamma + a_i^2}$$

$$\begin{aligned} H_i &\equiv \frac{1}{\epsilon}\left|\frac{\mathcal{A}_i'}{\mathcal{A}_i}\right|^2 \frac{\Phi\left(\frac{m_{J/\psi}}{m_{B_s^0}}, \frac{m_\phi}{m_{B_s^0}}\right)}{\Phi\left(\frac{m_{J/\psi}}{m_{B_s^0}}, \frac{m_{\overline{K}^{*0}}}{m_{B_s^0}}\right)} \frac{\mathcal{B}(B_s^0 \to J/\psi\,\overline{K}^{*0})_{\rm theo}}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)_{\rm theo}} \frac{f_i}{f_i'} \\ &= \frac{1 - 2a_i \cos\theta_i \cos\gamma + a_i^2}{1 + 2\epsilon a_i' \cos\theta_i' \cos\gamma + \epsilon^2 a_i'^2}\,, \end{aligned}$$

Backup: $B_s \to K^* K^*$ PDF

n	K_n	F_n
1	$\frac{1}{\Gamma_L}\lvert A_0\rvert^2\lvert\mathcal{M}_1(m_1)\rvert^2\lvert\mathcal{M}_1(m_2)\rvert^2$	$\cos^2\theta_1\cos^2\theta_2$
2	$\frac{1}{\Gamma_L}\lvert A_\parallel\rvert^2\lvert\mathcal{M}_1(m_1)\rvert^2\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\cos^2\varphi$
3	$\frac{1}{\Gamma_H}\lvert A_\perp\rvert^2\lvert\mathcal{M}_1(m_1)\rvert^2\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\sin^2\varphi$
4	$\frac{1}{\Gamma_L}\lvert A_\parallel\rvert\lvert A_0\rvert\cos\delta_\parallel\lvert\mathcal{M}_1(m_1)\rvert^2\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\cos\varphi$
5	0	$-\frac{1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\sin\varphi$
6	0	$-\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\sin 2\varphi$
7	$\frac{1}{2}(\frac{\lvert A_s^+\rvert^2}{\Gamma_H}+\frac{\lvert A_s^-\rvert^2}{\Gamma_L})\lvert\mathcal{M}_1(m_1)\rvert^2\lvert\mathcal{M}_0(m_2)\rvert^2$	$\frac{1}{3}\cos^2\theta_1$
8	$\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_0\rvert\mathcal{R}e(e^{i\delta_s^-}\mathcal{M}_1^*(m_2)\mathcal{M}_0(m_2))\lvert\mathcal{M}_1(m_1)\rvert^2$	$-\frac{2}{\sqrt{3}}\cos^2\theta_1\cos\theta_2$
9	$\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_\parallel\rvert\mathcal{R}e(e^{i(\delta_s^--\delta_\parallel)}\mathcal{M}_1^*(m_2)\mathcal{M}_0(m_2))\lvert\mathcal{M}_1(m_1)\rvert^2$	$-\frac{1}{\sqrt{6}}\sin 2\theta_1\sin\theta_2\cos\varphi$
10	$\frac{1}{\sqrt{2}}\frac{1}{\Gamma_H}\lvert A_s^+\rvert\lvert A_\perp\rvert\mathcal{I}m(e^{i(\delta_\perp-\delta_s^+)}\mathcal{M}_0^*(m_2)\mathcal{M}_0(m_2))\lvert\mathcal{M}_1(m_1)\rvert^2$	$\frac{1}{\sqrt{6}}\sin 2\theta_1\sin\theta_2\sin\varphi$
11	$\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_{ss}\rvert\mathcal{R}e(e^{i(\delta_s^--\delta_{ss})}\mathcal{M}_0^*(m_1)\mathcal{M}_1(m_1))\lvert\mathcal{M}_0(m_2)\rvert^2$	$\frac{2}{3\sqrt{3}}\cos\theta_1$
12	$\frac{1}{2}(\frac{\lvert A_s^+\rvert^2}{\Gamma_H}+\frac{\lvert A_s^-\rvert^2}{\Gamma_L})\lvert\mathcal{M}_0(m_1)\rvert^2\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{1}{3}\cos^2\theta_2$
13	$-\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_0\rvert\mathcal{R}e(e^{i\delta_s^-}\mathcal{M}_1^*(m_1)\mathcal{M}_0(m_1))\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{2}{\sqrt{3}}\cos\theta_1\cos^2\theta_2$
14	$-\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_\parallel\rvert\mathcal{R}e(e^{i(\delta_s^--\delta_\parallel)}\mathcal{M}_1^*(m_1)\mathcal{M}_0(m_1))\lvert\mathcal{M}_1(m_2)\rvert^2$	$\frac{1}{\sqrt{6}}\sin\theta_1\sin 2\theta_2\cos\varphi$
15	$\frac{1}{\sqrt{2}}\frac{1}{\Gamma_H}\lvert A_s^+\rvert\lvert A_\perp\rvert\mathcal{I}m(e^{i(\delta_\perp-\delta_s^+)}\mathcal{M}_0^*(m_1)\mathcal{M}_0(m_1))\lvert\mathcal{M}_1(m_2)\rvert^2$	$-\frac{1}{\sqrt{6}}\sin\theta_1\sin 2\theta_2\sin\varphi$
16	$-\frac{1}{\sqrt{2}}\frac{1}{\Gamma_L}\lvert A_s^-\rvert\lvert A_{ss}\rvert\mathcal{R}e(e^{i(\delta_s^--\delta_{ss})}\mathcal{M}_0^*(m_2)\mathcal{M}_1(m_2))\lvert\mathcal{M}_0(m_1)\rvert^2$	$-\frac{2}{3\sqrt{3}}\cos\theta_2$
17	$(\frac{\lvert A_s^+\rvert^2}{\Gamma_H}-\frac{\lvert A_s^-\rvert^2}{\Gamma_L})\mathcal{R}e(\mathcal{M}_1^*(m_1)\mathcal{M}_0^*(m_2)\mathcal{M}_0(m_1)\mathcal{M}_1(m_2))$	$-\frac{1}{3}\cos\theta_1\cos\theta_2$
18	$\frac{1}{\Gamma_L}\lvert A_{ss}\rvert^2\lvert\mathcal{M}_0(m_1)\rvert^2\lvert\mathcal{M}_0(m_2)\rvert^2$	$\frac{1}{9}$
19	$\frac{1}{\Gamma_L}\lvert A_{ss}\rvert\lvert A_0\rvert\mathcal{R}e(e^{i\delta_{ss}}\mathcal{M}_1^*(m_1)\mathcal{M}_1^*(m_2)\mathcal{M}_0(m_1)\mathcal{M}_0(m_2))$	$-\frac{2}{3}\cos\theta_1\cos\theta_2$
20	$\frac{1}{\Gamma_L}\lvert A_{ss}\rvert\lvert A_\parallel\rvert\mathcal{R}e(e^{i(\delta_{ss}-\delta_\parallel)}\mathcal{M}_1^*(m_1)\mathcal{M}_1^*(m_2)\mathcal{M}_0(m_1)\mathcal{M}_0(m_2))$	$-\frac{\sqrt{2}}{3}\sin\theta_1\sin\theta_2\cos\varphi$
21	0	$\frac{\sqrt{2}}{3}\sin\theta_1\sin\theta_2\sin\varphi$

Backup: B→$K_S\phi$ projections