Study of $B_s \to \varphi\varphi\varphi$

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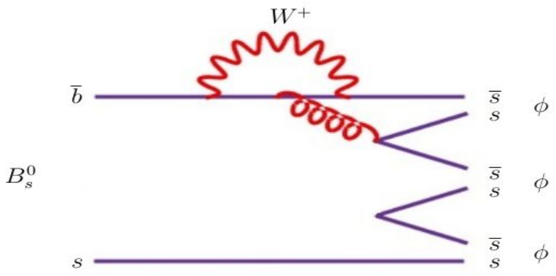
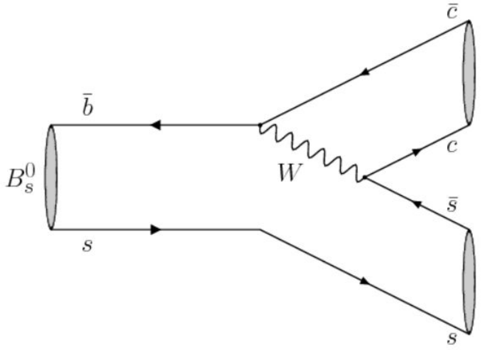
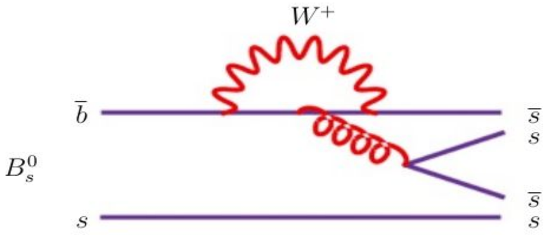
$B^0_s \to \varphi\varphi\varphi$ decay

- **$B^0_s \to \varphi\varphi\varphi$** possible processes:
    - three-body (non-resonant) penguin
    - two-body tree-level charmonium resonance decay with c-cbar → φφ



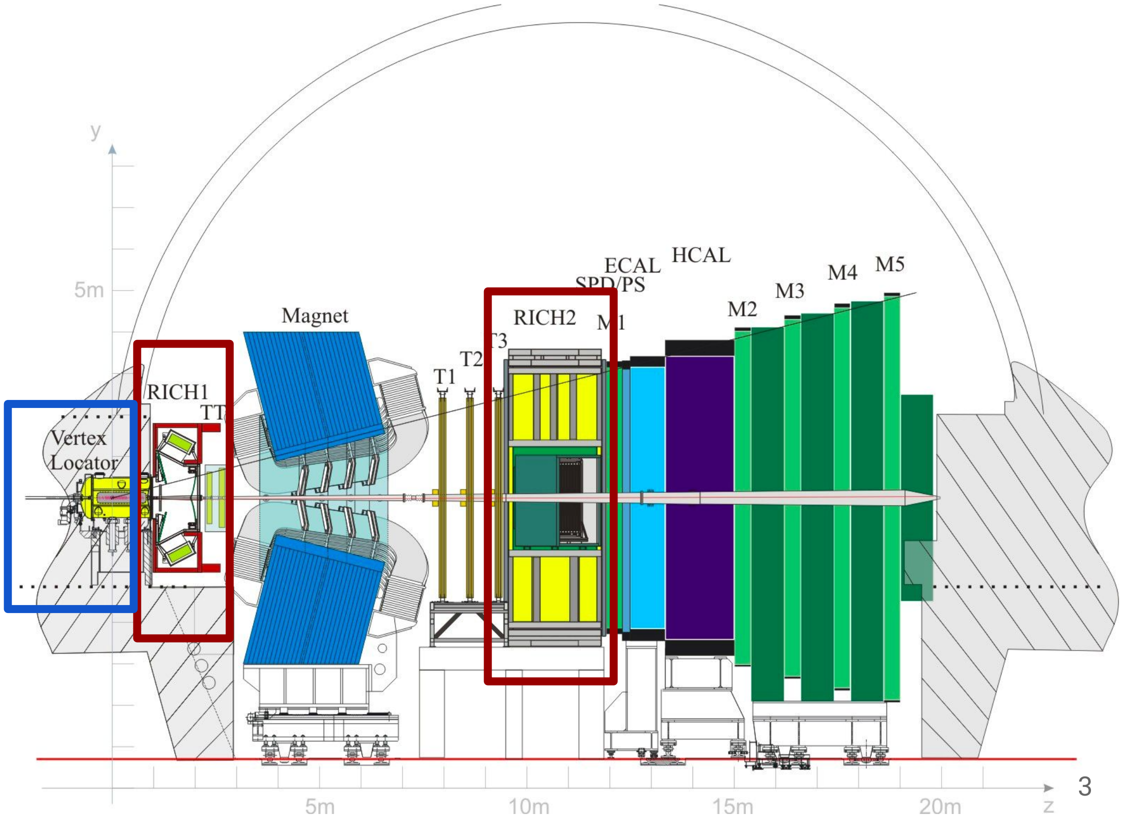


- **$B^0_s \to \varphi\varphi$** decay as normalization:
    - two-body penguin with heavy s-sbar resonance



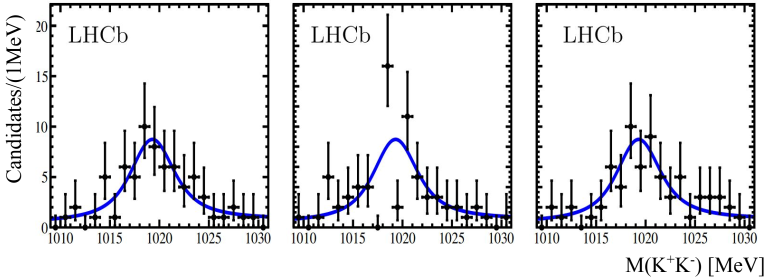
LHCb detector

- Decay vertex reconstruction - **Vertex Locator (VELO)**
- Kaon identification - **RICH detectors**
- Event selection - **Trigger system**

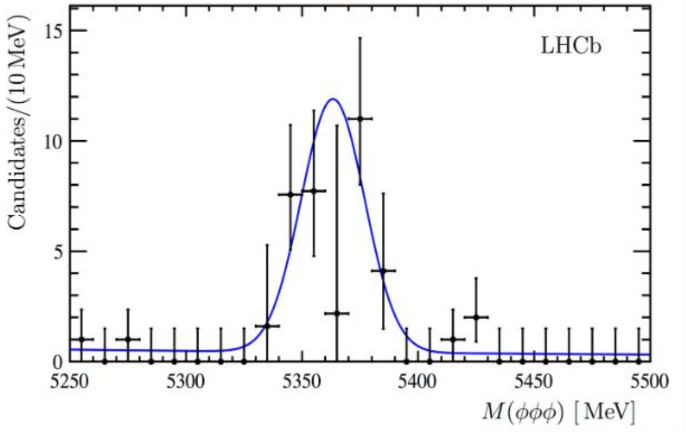


LHCb Run I measurement

- Previously (Run 1) $B^0_s \to \phi\phi\phi$ was discovered for the first time and branching fraction was measured ([Eur. Phys. J. C 77, 609 (2017)](#)):
- 3D fit of $M(K^+K^-_1) \times M(K^+K^-_2) \times M(K^+K^-_3)$ in bins of *M(KKKKKK)* to select true $\phi\phi\phi$ combinations



First evidence of $B^0_s \to \phi\phi\phi$ (**4.9σ**)



- $B^0_s \to \phi\phi$ used as a reference

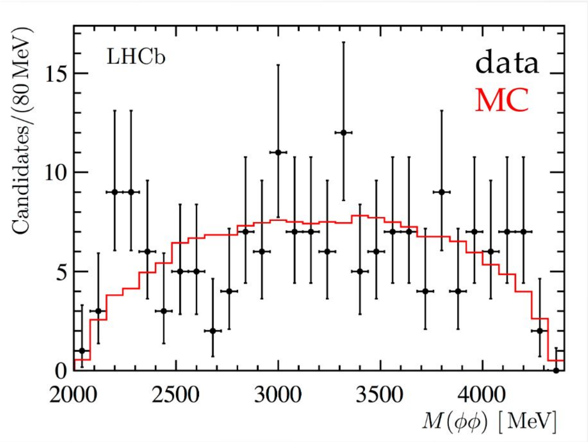
$$\frac{\mathcal{B}(B^0_s \to \phi\phi\phi)}{\mathcal{B}(B^0_s \to \phi\phi)} = \mathbf{0.117 \pm 0.030 \pm 0.015}$$

- using *BR*($B^0_s \to \phi\phi$) from JHEP 10, 053

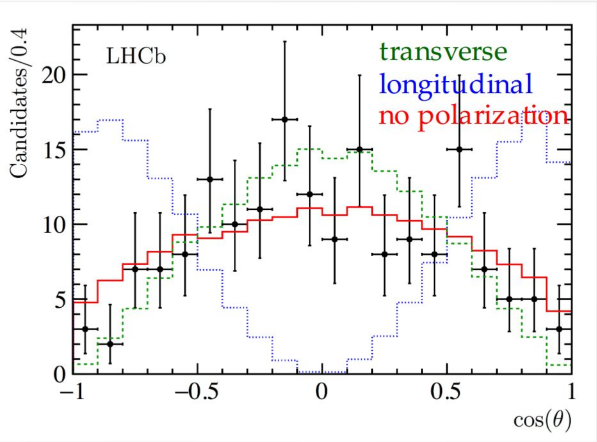
$$\mathcal{B}(B^0_s \to \phi\phi\phi) = (2.15 \pm 0.54 \pm 0.28 \pm 0.21) \times 10^{-6}$$

LHCb Run I measurement

- No significant resonant contribution was found



- Longitudinal polarization of φ does not describe the data:



Resonant structure in $B^0_s \rightarrow (\phi\phi)\phi$ is searched with the entire Run II data sample

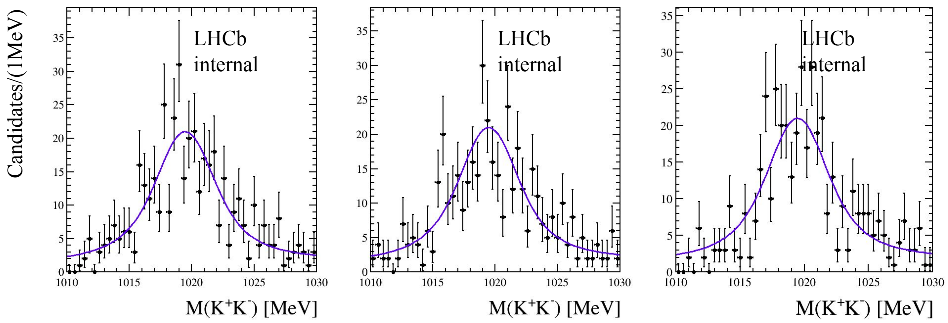
LHCb Run II measurement: data and selection

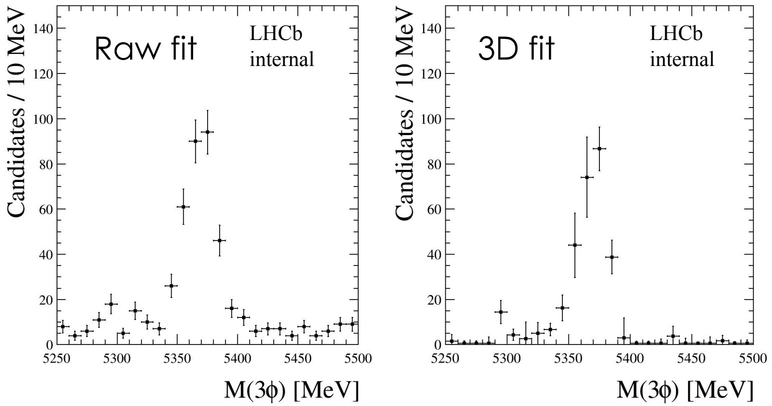
- $B^0_s \to \phi\phi\phi$ and $B^0_s \to \phi\phi$ data samples from 2016 – 2018 years
- Run II integrated luminosity is 5.6 fb-1, almost twice as much as in Run I
- Selection requirements:
  - Good-quality high-PT tracks identified as kaons
  - Kaons come from secondary vertex
  - Good-quality ϕ vertices
  - B^0_s mass and direction to PV constraints for resonant spectrum studies

Selection is motivated by Run I measurement

LHCb Run II measurement: strategy*

- 3D fit in bins of *M(KKKKKK)* to extract pure φφφ component
- The fit function includes φφφ, $\phi\phi K^+K^-$, $\phi K^+K^-K^+K^-$ and $K^+K^-K^+K^-K^+K^-$ contributions





- 2D fit procedure similarly is applied to the normalization channel

*Preliminary results

B^0_s branching fraction*

- $B^0_s \to \phi\phi\phi$ to $B^0_s \to \phi\phi$ branching fraction ratio:

$$\frac{\mathcal{B}(B^0_s \to \phi\phi\phi)}{\mathcal{B}(B^0_s \to \phi\phi)} = \frac{N_{B^0_s \to \phi\phi\phi}}{N_{B^0_s \to \phi\phi}} \times \frac{\varepsilon_{B^0_s \to \phi\phi}}{\varepsilon_{B^0_s \to \phi\phi\phi}} \times \frac{1}{\mathcal{B}(\phi \to K^+K^-)} = 0.23 \pm 0.04_{\text{stat}}$$

Efficiency from MC

- $B^0_s \to \phi\phi$ branching fraction is

$$\mathcal{B}(B^0_s \to \phi\phi) = (1.87 \pm 0.15) \times 10^{-5}$$

- $B^0_s \to \phi\phi\phi$ branching fraction:

$$\mathcal{B}(B^0_s \to \phi\phi\phi) = (4.2 \pm 0.7_{\text{stat}}) \times 10^{-6}$$

*Preliminary results

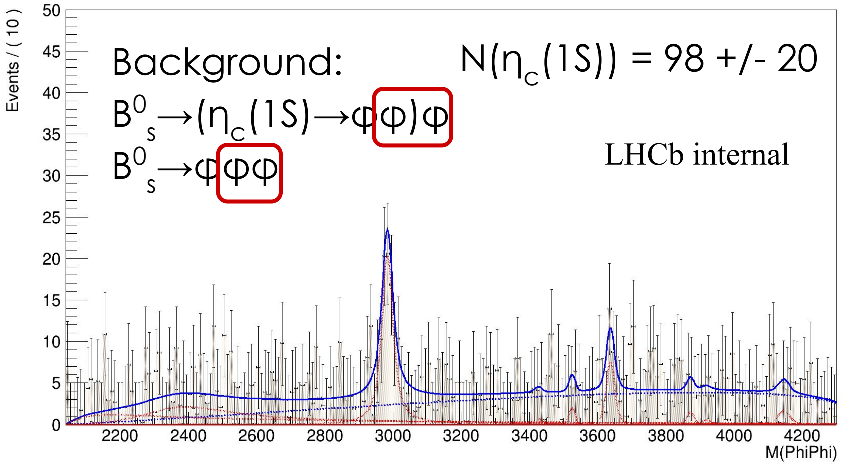
Search for $B^0_s \to (\eta_c(1S) \to \phi\phi)\phi$*

- Fit to invariant mass of φφ from B0s→(ηc(1S)→φφ)φ
- Considered resonances ⇒
- Background shape is being studied

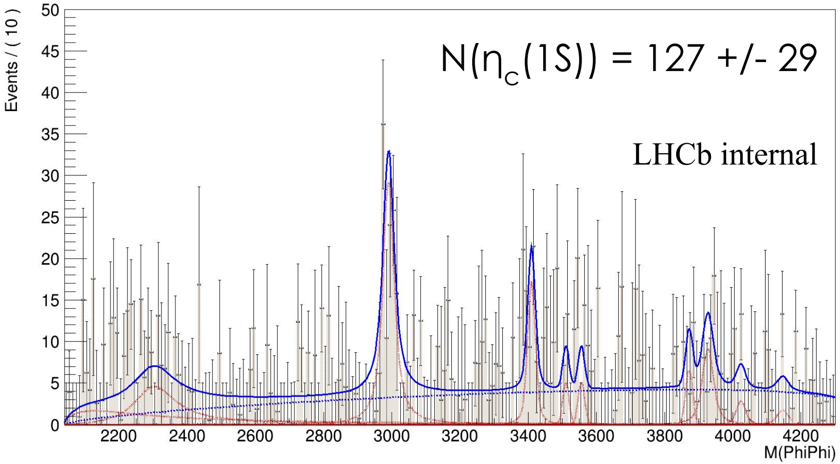
Resonance	Mass, MeV/c^2	Γ, MeV/c^2	J^{CP}
$f_2(2010)$	2011^{+60}_{-80}	202 ± 60	2^{++}
$a_4(2040)$	1995^{+10}_{-8}	257^{+25}_{-23}	4^{++}
$f_4(2050)$	2018 ± 11	237 ± 18	4^{++}
$f_2(2300)$	2297 ± 28	149 ± 40	2^{++}
$f_2(2340)$	2345^{+50}_{-40}	322^{+70}_{-60}	2^{++}
$\eta_c(1S)$	2983.9 ± 0.5	32.0 ± 0.8	0^{-+}
$\chi_{c0}(1P)$	3414.71 ± 0.30	10.8 ± 0.6	0^{++}
$\chi_{c1}(1P)$	3510.67 ± 0.05	0.84 ± 0.04	1^{++}
$h_c(1P)$	3525.38 ± 0.11	0.7 ± 0.4	1^{+-}
$\chi_{c2}(1P)$	3556.17 ± 0.07	1.97 ± 0.09	2^{++}
$\eta_c(2S)$	3637.6 ± 1.2	$11.3^{+3.2}_{-2.9}$	0^{-+}
$\chi_{c1}(3872)$	3871.69 ± 0.17	< 1.2	1^{++}
$Z_c(3900)$	3886.6 ± 2.4	28.2 ± 2.6	1^{+-}
$X(3915)$	3918.4 ± 1.9	20 ± 5	0 *or* 2^{++}
$\chi_{c2}(3930)$	3927.2 ± 2.6	24 ± 6	2^{++}
$X(4020)$	4024.1 ± 1.9	13 ± 5	$?^{?+}$
$\chi_{c1}(4140)$	4146.8 ± 2.4	22^{+8}_{-7}	1^{++}

*Preliminary results

Resonant structure studies*



φφ mass spectrum after 3+1D fit in bins (without kinematic constraints)



φφ mass spectrum after 3D fit in bins (with B_s mass and direction constraints)

- Left plot comprises true φφ pairs from true $B^0_s \to \phi\phi\phi$ decays; Right plot aims at better peak resolutions
- Only significant contribution is the one from η_c(1S)
- Both approaches yield consistent numbers of η_c(1S) signal yield

*Preliminary results

$B^0_s \to \eta_c(1S)\phi$ branching fraction*

Efficiency from MC

- From the fit:

$$\frac{\mathcal{B}(B^0_s\to\eta_c(1S)\phi)}{\mathcal{B}(B^0_s\to\phi\phi\phi)} = \frac{N_{B^0_s\to\eta_c(1S)\phi}}{N_{B^0_s\to\phi\phi\phi}} \times \frac{\epsilon_{B^0_s\to\phi\phi\phi}}{\epsilon_{B^0_s\to\eta_c(1S)\phi}} \times \frac{1}{\eta_c(1S)\to\phi\phi} = 245 \pm 56$$

- Using our $B^0_s \to \phi\phi\phi$ branching fraction:

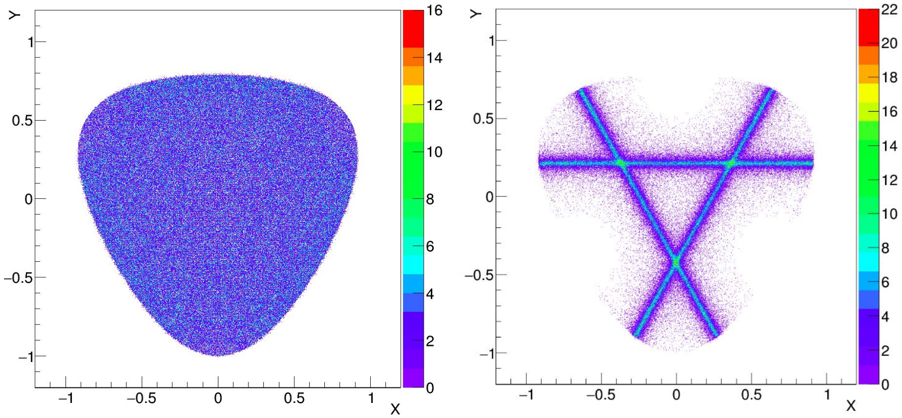
$$\mathcal{B}(B^0_s \to \eta_c(1S)\phi) = (10.4 \pm 2.4_{stat}) \times 10^{-4}$$

- Previously measured by LHCb (JHEP 2017 021) with $\eta_c(1S)$ decaying to p-pbar:

$$\mathcal{B}(B^0_s \to \eta_c\phi) = (5.01 \pm 0.53 \pm 0.27 \pm 0.63) \times 10^{-4}$$

*Preliminary results

Symmetrized Dalitz plot*

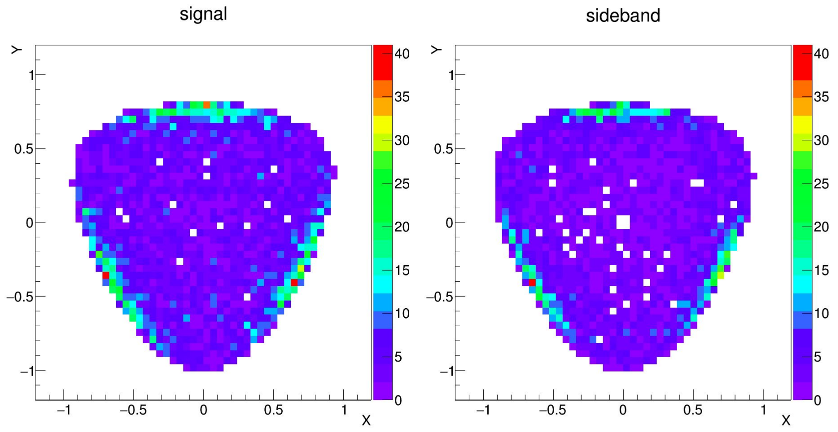


Symmetrized Dalitz plot: [PhysRev.133.B1201]

$$X = \frac{\sqrt{3}}{2m_{B_s^0}Q}(u - t) \quad Y = \frac{3}{2m_{B_s^0}Q}((m_{B_s^0} - m_\phi)^2 - s) - 1$$

← From the $B^0_s \to \phi\phi\phi$ and $B^0_s \to \eta_c(\phi\phi)\phi$ Monte-Carlo respectively

From the $B^0_s \to \phi\phi\phi$ data→



Fit of true B^0_s signal in bins of Dalitz plot

Summary

- The $B^0_s \to \phi\phi\phi$ analysis with twice as much data as in Run 1 is in progress
- Resonant structure is studied
- The significant amount of $\eta_c(1S)$ resonance in this decay was found for the first time
- Symmetrized Dalitz plot study is in progress