Vertex resolution in B_s^0 decays under different IDEA Delphes configurations

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FCC-ee Physics Performance meeting

Introduction

- Use *k4SimDelphes* with EvtGen to generate:
  - 10k $B_s^0 \to (J/\psi \to \mu^+\mu^-)(\phi \to K^+K^-)$ decays
  - 5k $B_s^0 \to (D_s^- \to K^-K^+\pi^-)K^+$ decays

- Analyse output using *VertexExamples* code in *HEP-FCC/FCCeePhysicsPerformance* repo to run vertex fits

- Full covariance matrices for the inputs used in vertex fits
  - In $B_s^0 \to D_s^- K^+$, vertex fit performed to D_s^- first and full information on D_s^- *pseudo-track* passed to the B_s^0 vertex fit

- **Aim:** study the vertex resolution as a function of several detector parameters in IDEA Delphes, using independent samples generated with different cards

Delphes parameters varied

Parameter	Range considered [default]
r_1 of first vtx. layer [mm]	4 – 17 [17]
r_2 of second vtx. layer [mm]	6 – 23 [23], $r_1 = 4$ mm
Beam pipe thickness [% X_0]	0.34 (CLD), 0.48 (CDR), 0.59 (MDI) [0.34]
Single hit resolution [μm]	1 – 10 [3]
Inner 3 vtx. layer thickness [μm]	50 – 500 [280]
Inner 3 vtx. layer X_0	0.02 – 0.2 [0.0937]

Assessing the resolution

- Run vertex fits on MC samples generated using different Delphes cards, where parameters of interest are varied away from the IDEA default

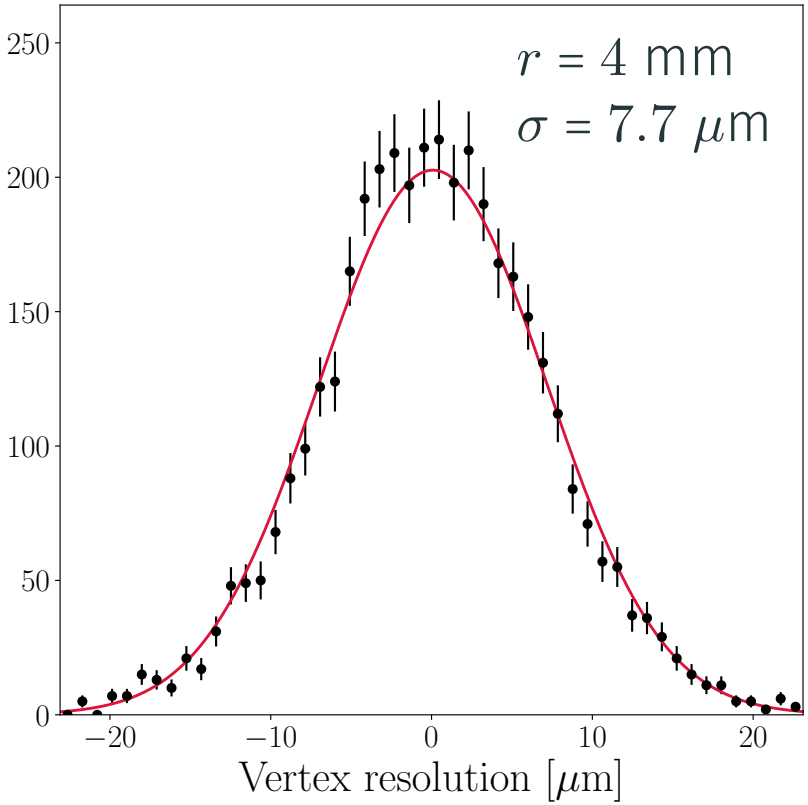
- Vertex fits measure (x, y, z) coordinate of B_s^0 decay vertex - calculate $r = \sqrt{x^2 + y^2 + z^2}$

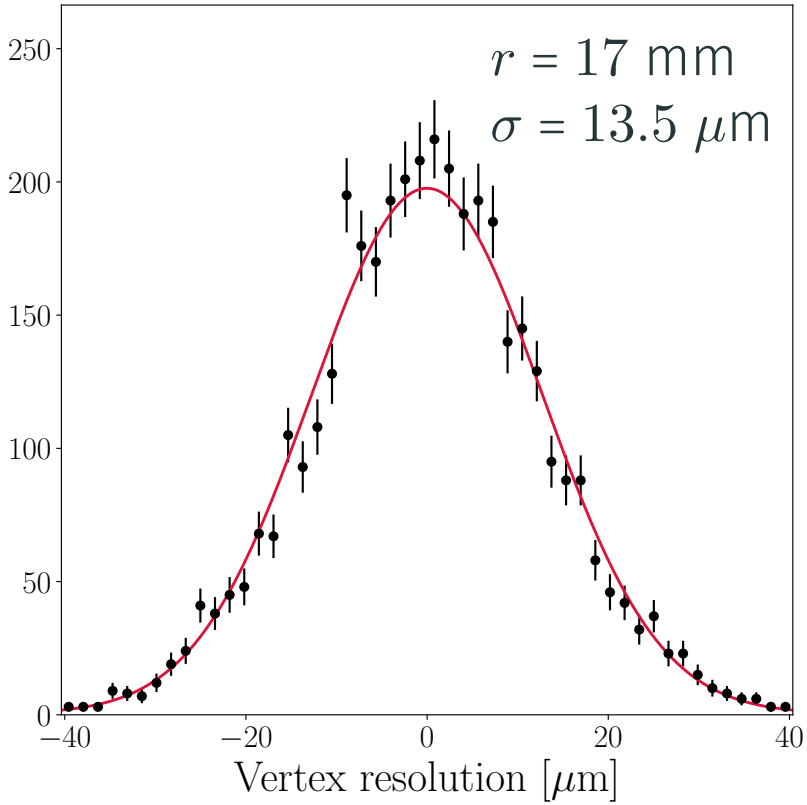
- Compare r with the MC-truth r_T, and fit $\delta = r - r_T$ with a double-Gaussian PDF
    - Gaussians share a mean and have independent widths, σ_1 and σ_2

- Vertex resolution given by $\sigma = f_1\sigma_1 + (1 - f_1)\sigma_2$, where f_1 is the fraction of the first Gaussian which freely varies in each fit

Example fits

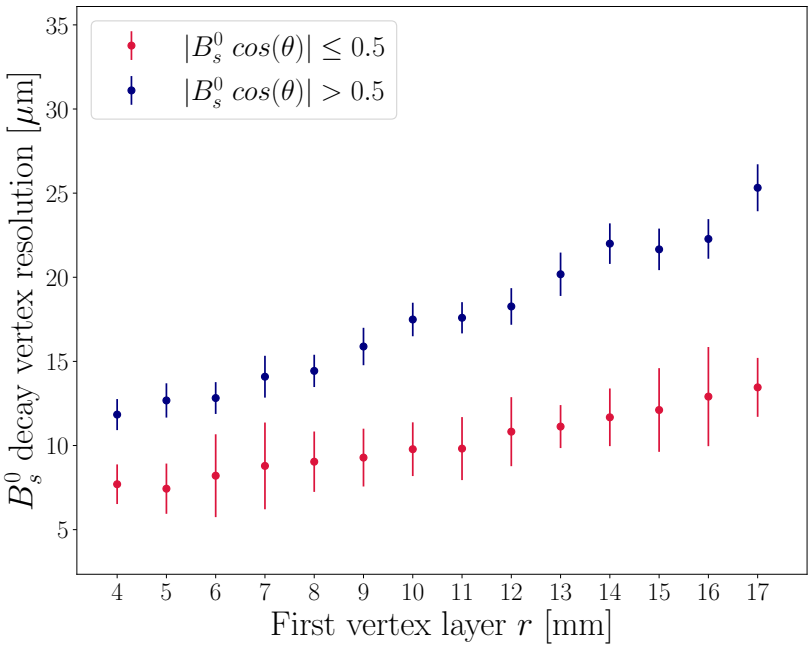
- Varying radial distance of first vertex detector layer
- Show $B_s^0 \to J/\psi\phi$ decays in central region, $|\cos(\theta)| \leq 0.5$
  - θ is the angle of the true B_s^0 direction relative to the beam axis



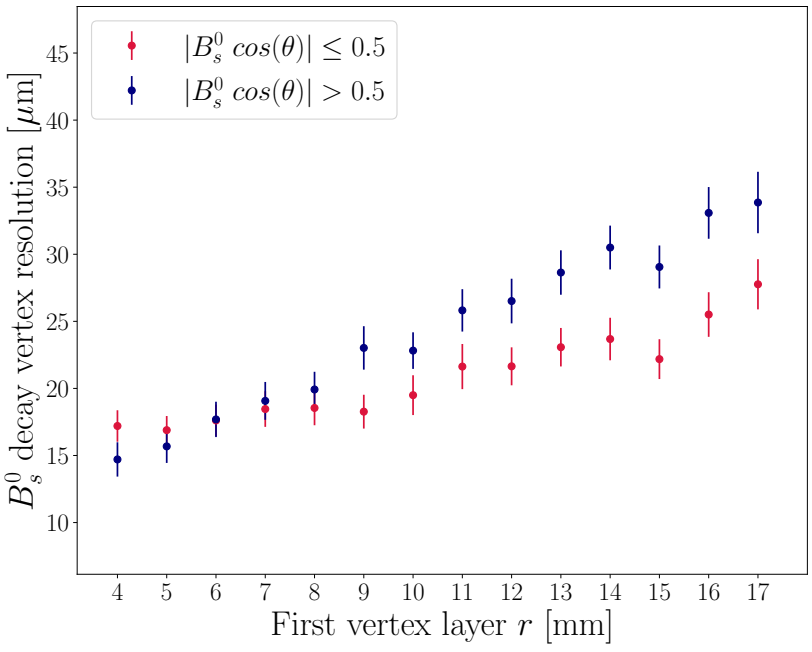


Radial distance (r_1) of first vertex layer [default = 17]

$B_s^0 \to J/\psi\phi$



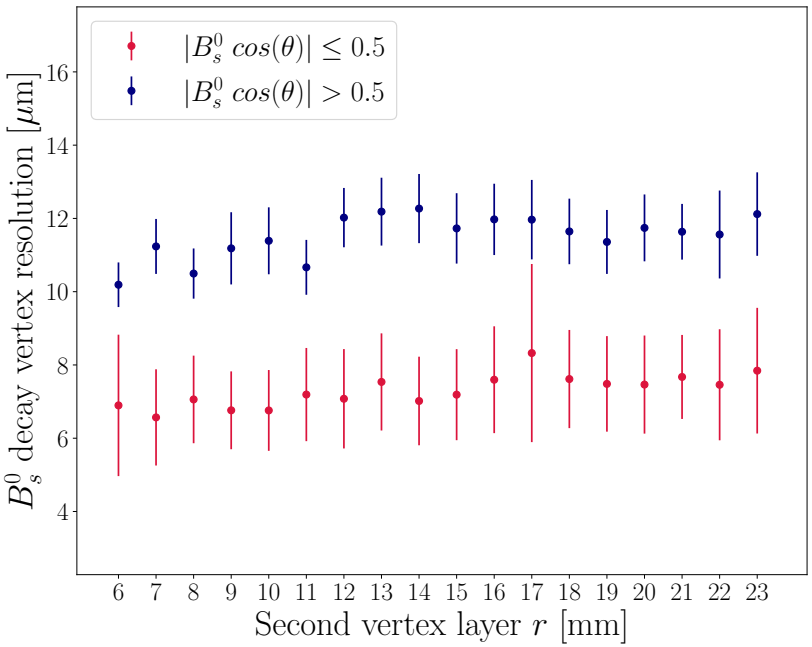
$B_s^0 \to D_s^- K^+$



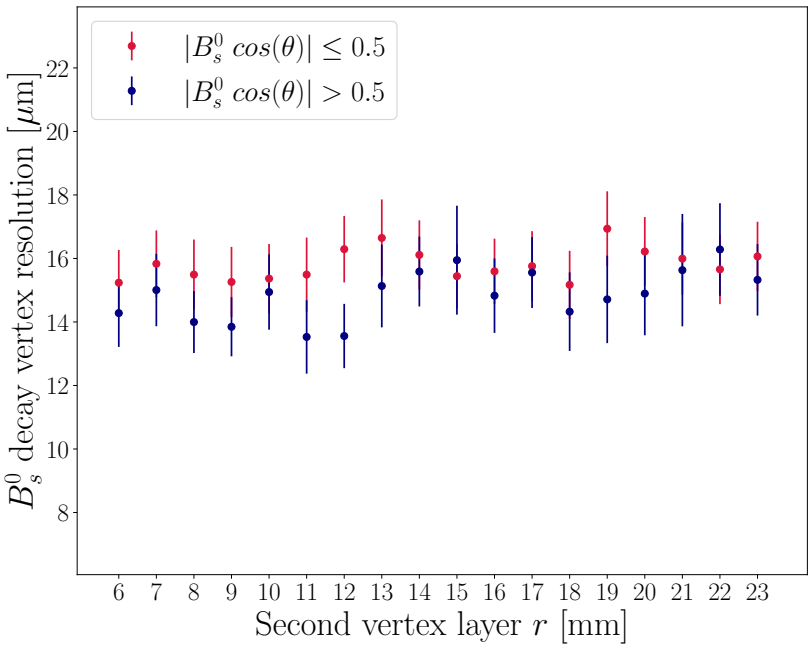
- More central B's are shown in red, and more forward B's in blue (defined according to $\cos(\theta)$ values)

r_2 of second vertex layer [default = 23], $r_1 = 4$ mm

$B_s^0 \to J/\psi\phi$



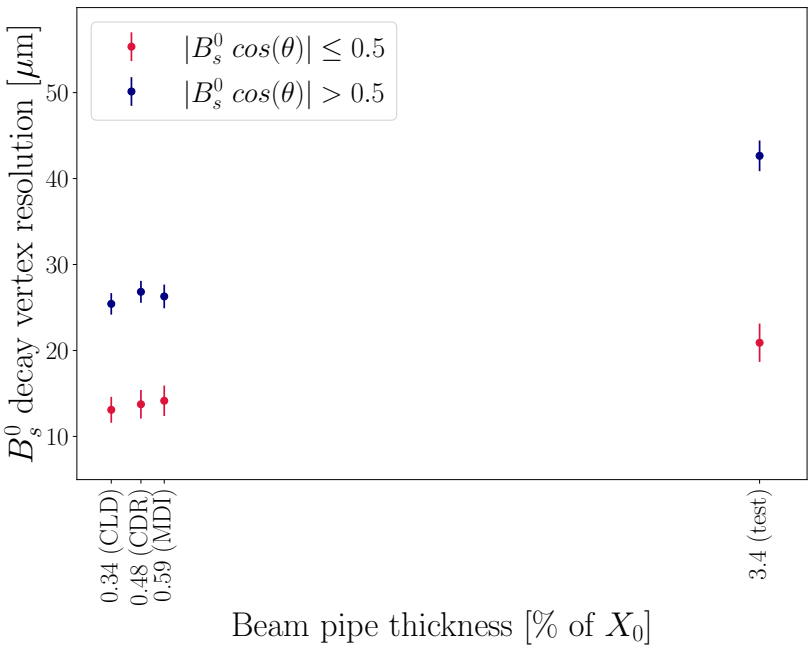
$B_s^0 \to D_s^- K^+$



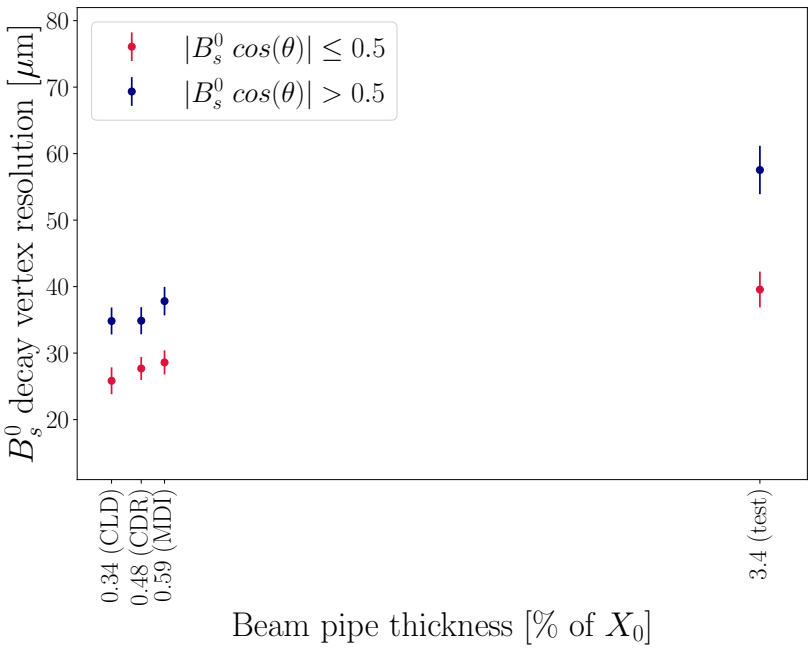
- Vary second vertex layer radial distance, **maintaining first layer radius at 4 mm**

Beam pipe thickness [default = 0.34]

$B_s^0 \to J/\psi\phi$



$B_s^0 \to D_s^- K^+$



- Some dependence on beam pipe - a test point run with very large thickness verifies that degradation is occurring

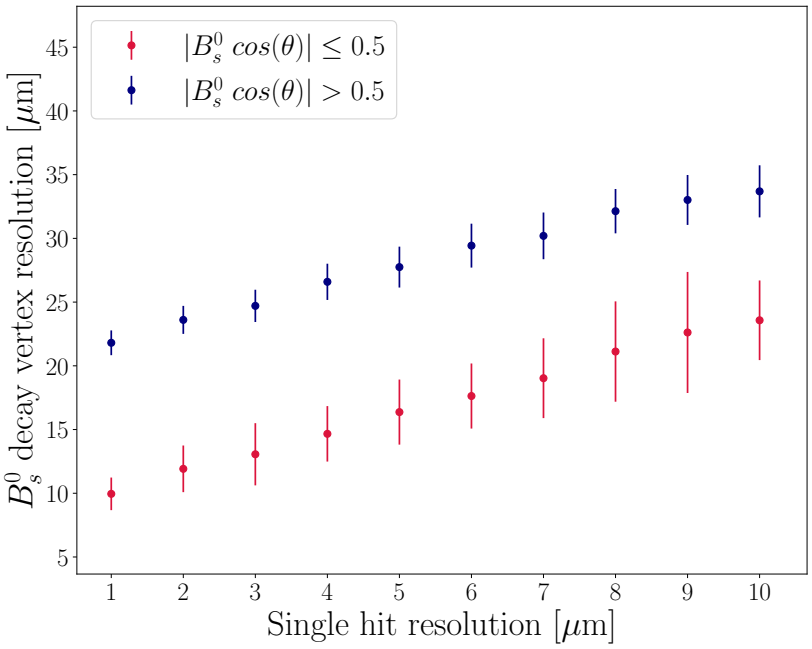
Aside: CDR beam pipe design

- CDR design features like 15 mm separation from beam line and beryllium thickness of 12 mm are used in default Delphes
- Perhaps it is possible to add the gold layer (control synchrotron radiation) and water (cooling) to Delphes?

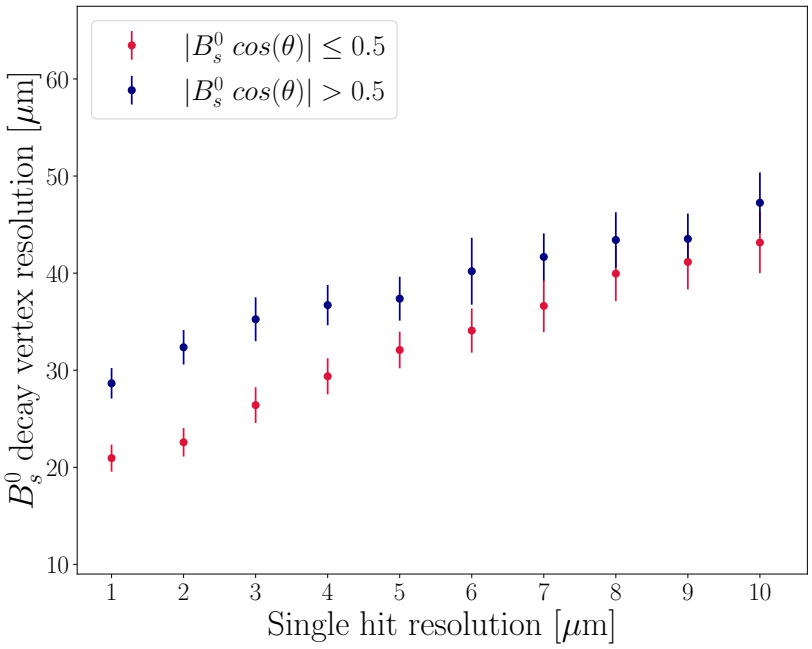
Image credit: Nicola Bacchetta

Single hit resolution [default = 3]

$B_s^0 \to J/\psi\phi$

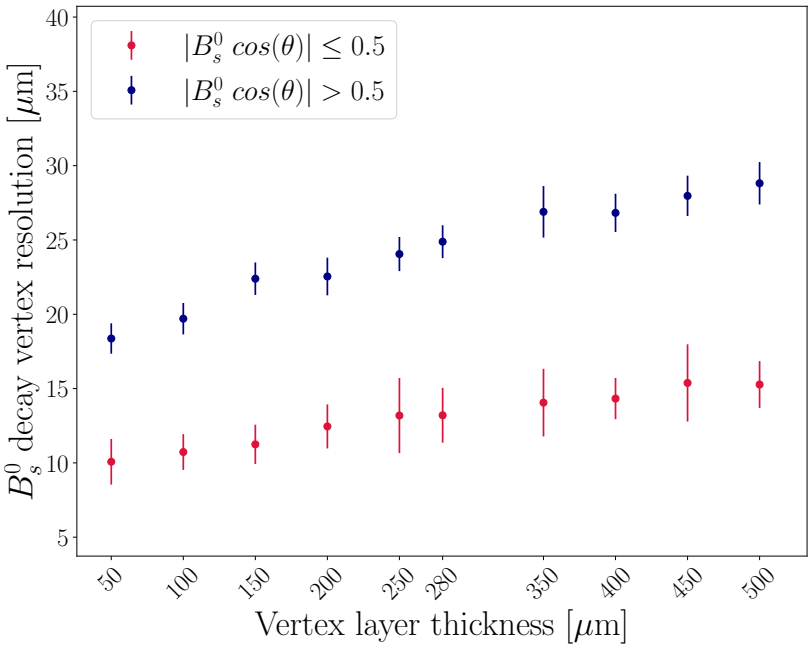


$B_s^0 \to D_s^- K^+$

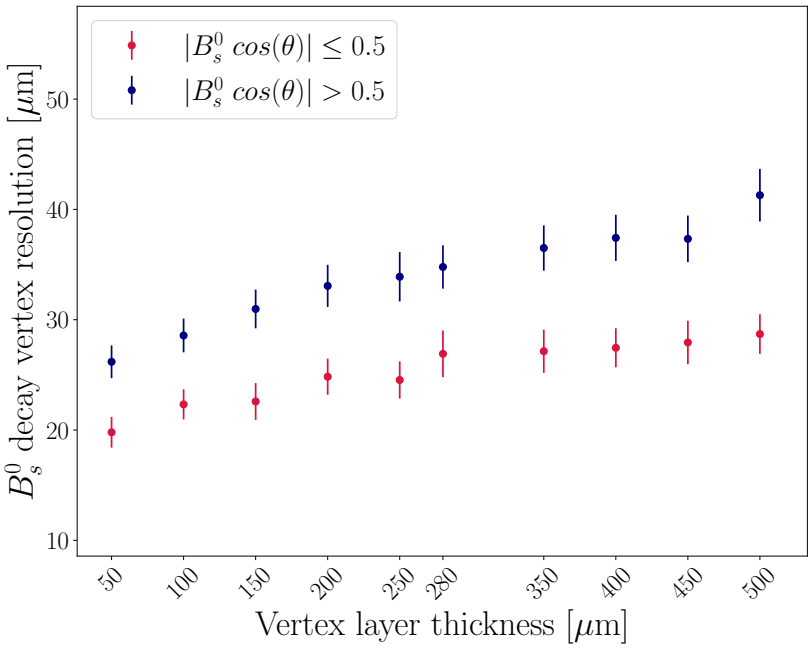


Inner 3 vertex layer thickness [default = 280]

$B_s^0 \to J/\psi\phi$

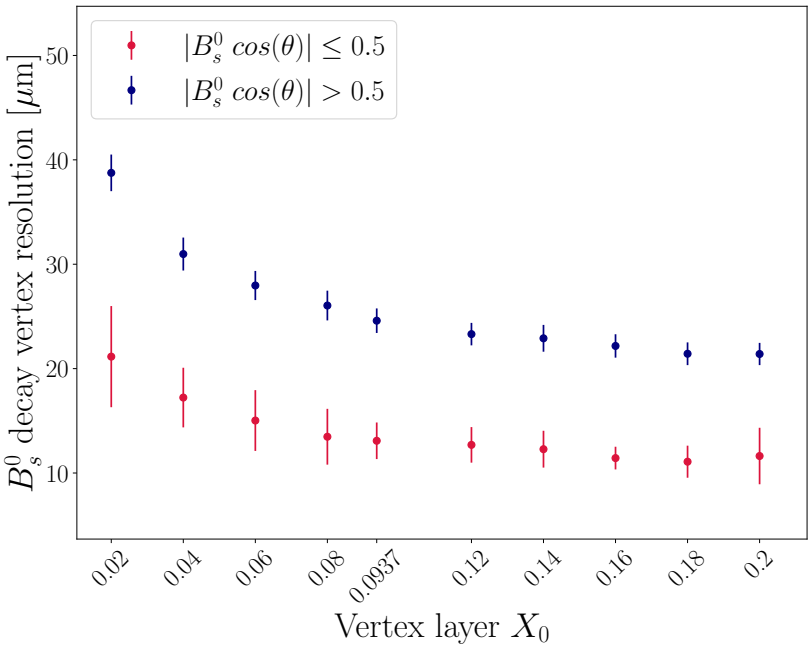


$B_s^0 \to D_s^- K^+$

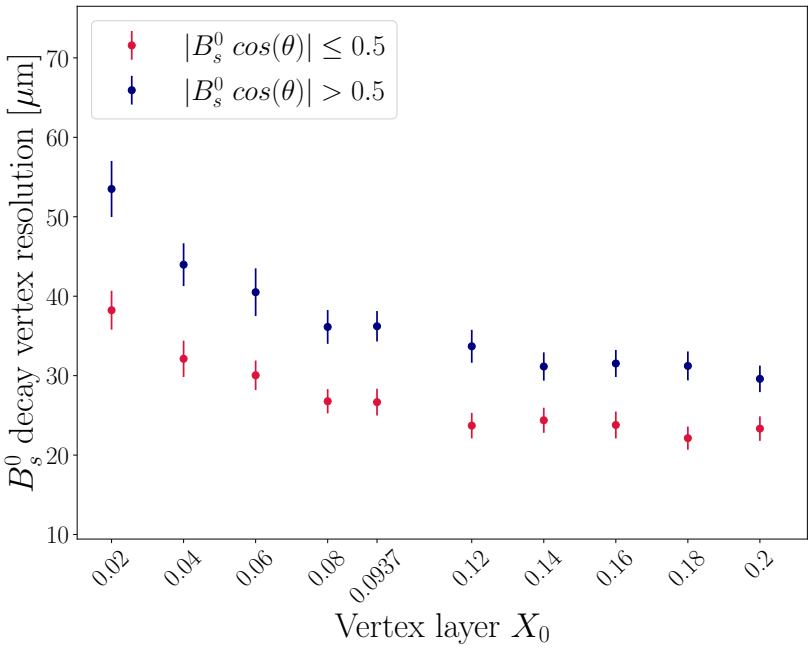


Inner 3 vertex layer X_0 [default = 0.0937]

$B_s^0 \to J/\psi\phi$



$B_s^0 \to D_s^- K^+$

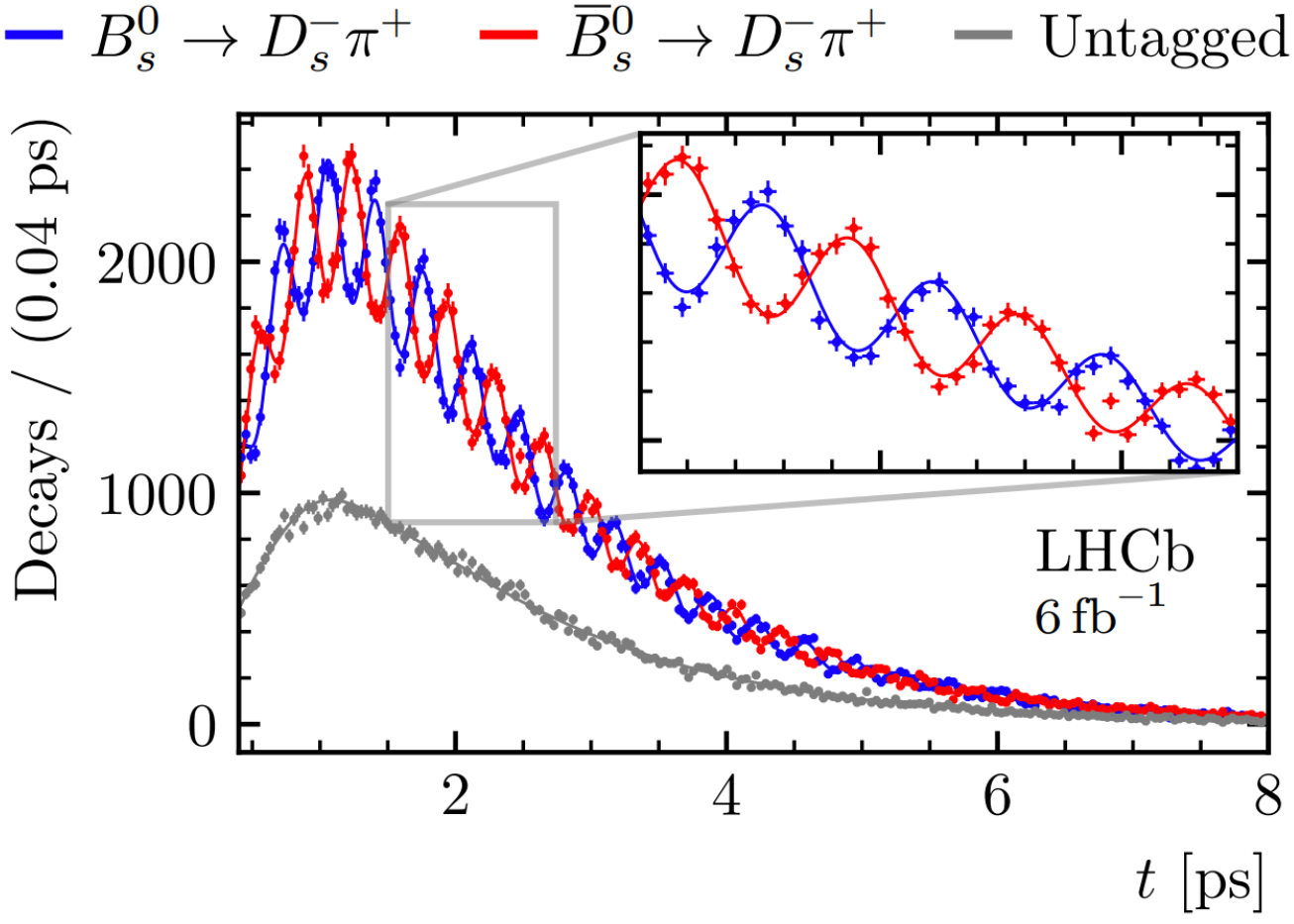


Summary

- Vertex precision better for more central B's - difference larger for $B_s^0 \to J/\psi\phi$
- Trends observed when each of the Delphes parameters are varied - general trend directions make sense
- Need to study limiting precision of the vertexing - look at performance with all parameters set to best-case values
  - e.g. why is the best resolution 8 μm with a 4 mm first layer r?
- **Vertex resolution key for flavour**, and B_s^0 modes in particular - feeds directly into flight distance resolution and thus lifetime resolution
  - Excellent lifetime resolution needed in order to resolve mixing ($\Delta m_s = 17.7656 \pm 0.0057$ ps^{-1} from LHCb-PAPER-2021-005)
  - In this measurement, lifetime resolution was **47 fs**

Vertex resolution - a key performance metric

- Measurement of Δm_s in $B_s^0 \to D_s^- \pi^+$ decays [LHCb-PAPER-2021-005]



Vertex resolution - a key performance metric

- $B_s^0 \to D_s^- \pi^+$ decay length (l) resolution in LHCb simulation is ~ 160 μm (without any fancy decay tree fitting)

- Proper time $t = l \times \frac{m}{p}$, so lifetime resolution of 47 fs relies on good l and p resolution

- Vertex resolutions shown today compare favourably to LHCb performance
  - We must understand how to achieve the best possible performance, to achieve superb t resolution