Bs Oscillation in standard model

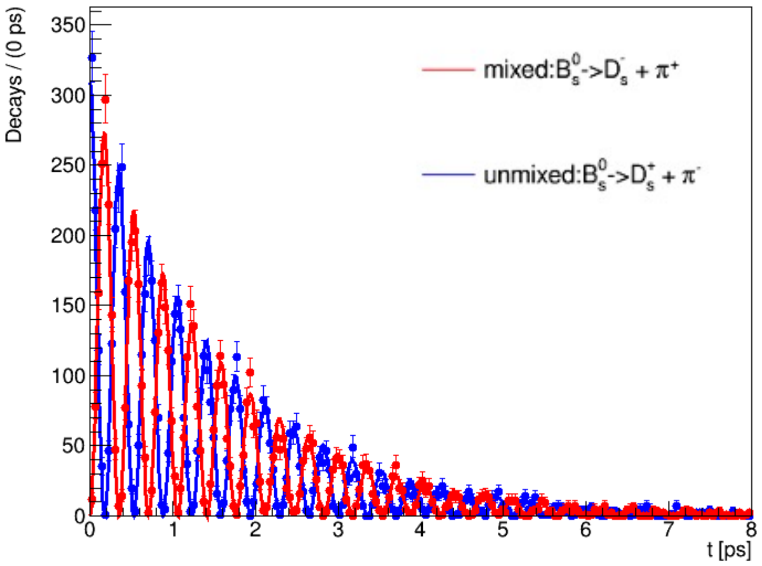
1. In standard model, B_s^0 decay time distribution without detector effects should be:

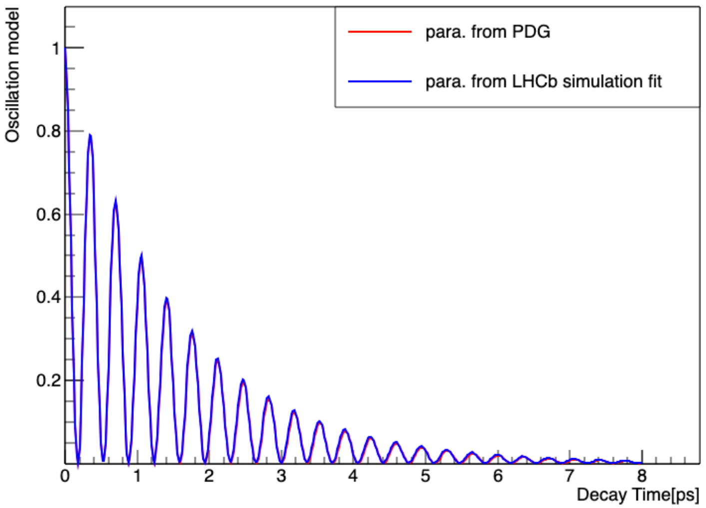
$$P(t) \approx e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + C\cos(\Delta m_s t)\right],$$

For the three parameters, we have PDG values here:

Where $\Gamma_s = 0.66ps^{-1}$ *is the* B_s^0 *decay width,*
$\Delta\Gamma_s = (0.085 \pm 0.004)ps^{-1}$ *is the decay width difference between the heavy and light mass eigenstates, a small quantity.*
$\Delta m_s = (17.7683 \pm 0.0051)ps^{-1}$. *is the frequency of* B_s^0 *oscillation.*

2. LHCb already reported a precise measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency, we show the LHCb simulation for $B_s^0 \rightarrow D_s^-\pi^+$[no oscillation] and $B_s^0 \rightarrow D_s^+\pi^-$[oscillation]. It has the same shape as standard model basically.



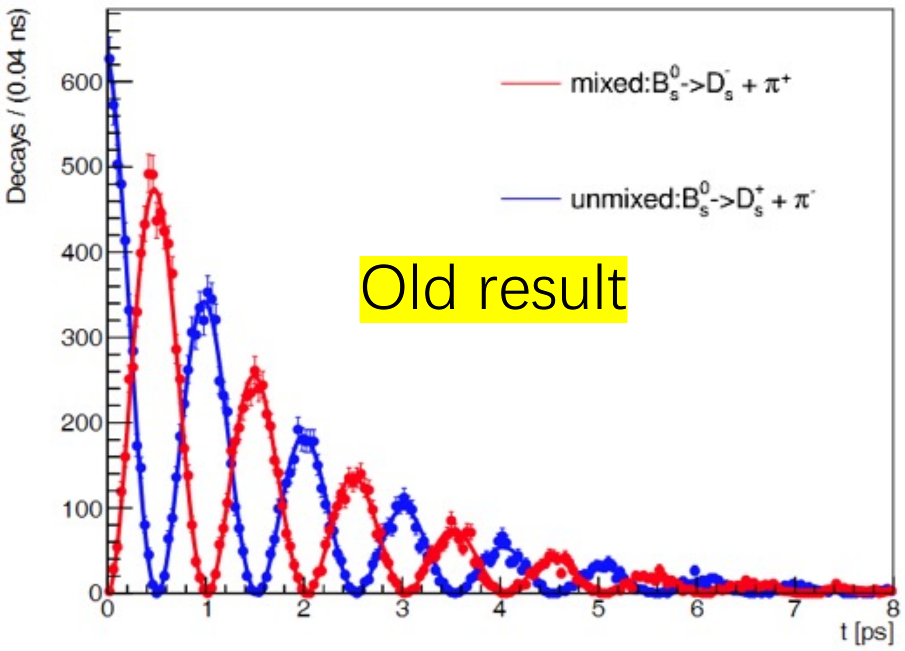


Source	PDG	LHCb simulation
$\Gamma_s(ps^{-1})$	0.66	0.65
$\Delta\Gamma_s(ps^{-1})$	0.085	0.162
$\Delta m_s(ps^{-1})$	17.7683	17.806

Lifetime: $\tau = 1/\Gamma_s = 1.515ps$
Oscillation period: $T_s = 2\pi/\Delta m_s = 0.353ps$

Bs Oscillation in Whizard

1. The B_s^0 oscillation in Whizard generator report a different frequency as PDG and LHCb results. We show the B_s^0 decay time distribution fit in Whizard here and compare the three parameters with PDG and LHCb simulation.



$$P(t) \approx e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + C\cos(\Delta m_s t)\right],$$

Source	PDG	LHCb simulation	Whizard output
$\Gamma_s(ps^{-1})$	0.66	0.65	0.61
$\Delta\Gamma_s(ps^{-1})$	0.085	0.162	0.152
$\Delta m_s(ps^{-1})$	17.7683	17.806	6.191

In Whizard:

Lifetime: $\tau = 1/\Gamma_s = 1.639ps$ ($\sim 1.515ps$)

Oscillation period: $T_s = 2\pi/\Delta m_s = 1.014ps$ ($> 0.353ps$)

Question for Whizard:

The oscillation frequency is smaller than standard value, around 1/3.

Bs Oscillation in Pythia6

1. In existed Whizard sample, we use Whizard1.95, and Pythia6 for shower/hadrons.
2. In Pythia6, mixing parameter could be set by 'PARJ(77)=26.9'(17.76/0.66)

MSTJ(26) : (D = 2) inclusion of B–$\overline{\mathrm{B}}$ mixing in decays.

= 0 : no.

= 1 : yes, with mixing parameters given by PARJ(76) and PARJ(77). Mixing decays are not specially marked.

= 2 : yes, as = 1, but a B ($\overline{\mathrm{B}}$) that decays as a $\overline{\mathrm{B}}$ (B) is marked as K(I,1) = 12 rather than the normal K(I,1) = 11.

PARJ(76) : (D = 0.7) mixing parameter $x_d = \Delta M/\Gamma$ in B^0–$\overline{\mathrm{B}}^0$ system.

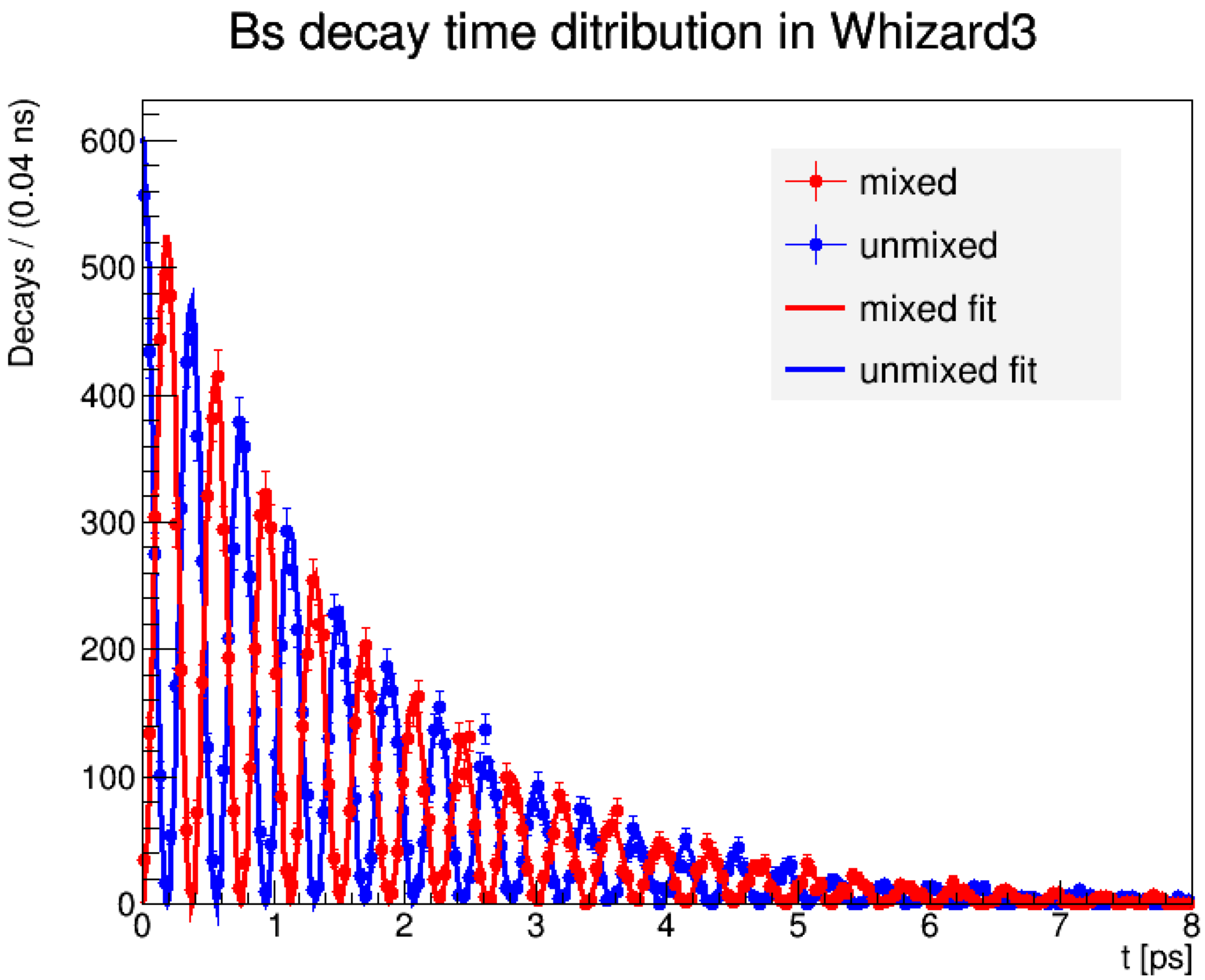
PARJ(77) : (D = 10.) mixing parameter $x_s = \Delta M/\Gamma$ in B_s^0–$\overline{\mathrm{B}}_s^0$ system.

PARJ(80) - PARJ(90) : parameters for time-like parton showers, see section 10.4.

PARJ(91) : (D = 0.020 GeV) minimum particle width in PMAS(KC,2), above which parti-

$ps_PYTHIA_PYGIVE = "PARJ(77)=26.9; PMAS(25,1)=125.0; PMAS(25,2)=0.3605E-02;MSTJ(41)=2; MSTU(22)=20; MSTJ(28)=2; PARJ(21)=0.40000; PARJ(41)=0.11000; PARJ(42)=0.52000; PARJ(81)=0.25000;PARJ(82)=1.90000; MSTJ(11)=3; PARJ(54)=-0.03100; PARJ(55)=-0.00200;PARJ(1)=0.08500; PARJ(3)=0.45000; PARJ(4)=0.02500; PARJ(2)=0.31000;PARJ(11)=0.60000; PARJ(12)=0.40000; PARJ(13)=0.72000;

Bs Oscillation in Whizard3+Pythia6



PARJ(77)=17.76/0.66=26.9
+ original settings

Source	PDG	LHCb simulation	new Whizard output
$\Gamma_s(\mathrm{ps}^{-1})$	0.66	0.65	0.64
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.085	0.162	0.235
$\Delta m_s(\mathrm{ps}^{-1})$	17.7683	17.806	16.694 ~ 5%

$y_s = \Delta\Gamma_s/2\Gamma_s = 0.185,$

$x_s = \Delta m_s/\Gamma_s = 26.223,$ ~ 2.5%

Chain Model:

$mix: \overline{B_S^0} \rightarrow D_S^- \pi^+$

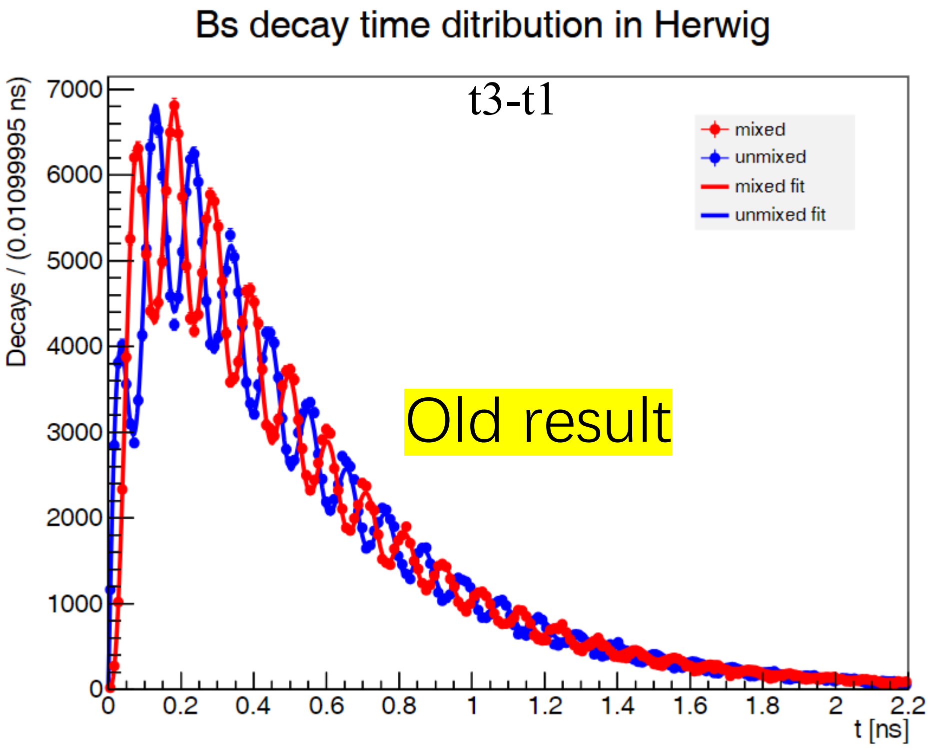
$unmix: B_S^0 \rightarrow D_S^- \pi^+$

Bs Oscillation in Herwig

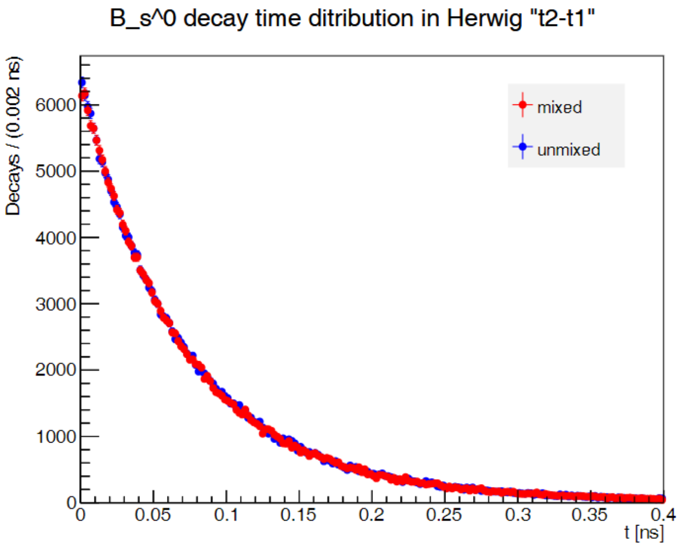
1. The B_s^0 oscillation in Herwig generator report different frequency, oscillation models, and time scale as PDG and LHCb results. We show the B_s^0 decay time distribution fit in herwig here.

e.g. $mix: \overline{B_S^0} \to B_S^0 \to D_S^- \pi^+$ $unmix: B_S^0 \to B_S^0 \to D_S^- \pi^+$

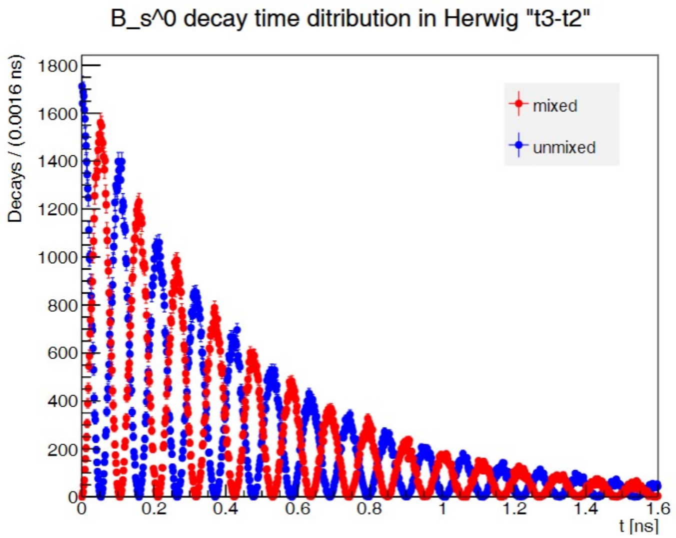
creation time: t1 t2 t3



$f(t) \propto \exp(-at) \otimes P(t)$



exp(−at)



$$P(t) \approx e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + C\cos(\Delta m_s t)\right],$$

Question for Herwig:

1. The time scale is different as standard. 2.2ns>>8ps
2. “t3-t1” should have a similar model as standard, but only “t3-t2” has.

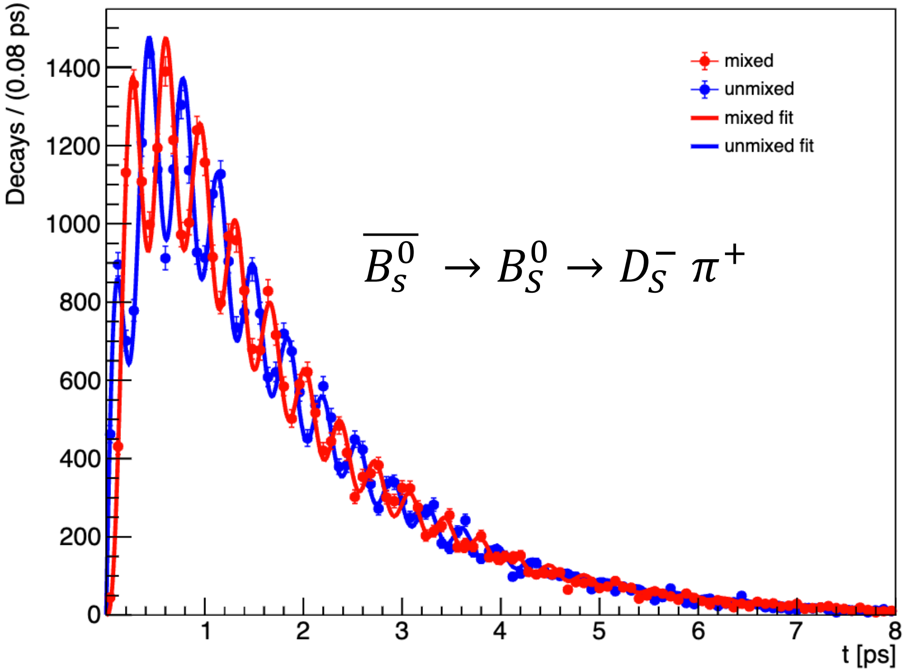
Bs Oscillation in EvtGen

1. In existed Herwig sample, we use Herwig7.2.2(latest is 7.3.0), and starting with 7.1, Evtgen used for a simulation of B-hadron decays.
2. In EvtGen, c=1, such that mass, energy and momentum are all measured in units of [GeV]. Similarly, time and space have units of [mm], so 2.2mm/c = 7.3ps

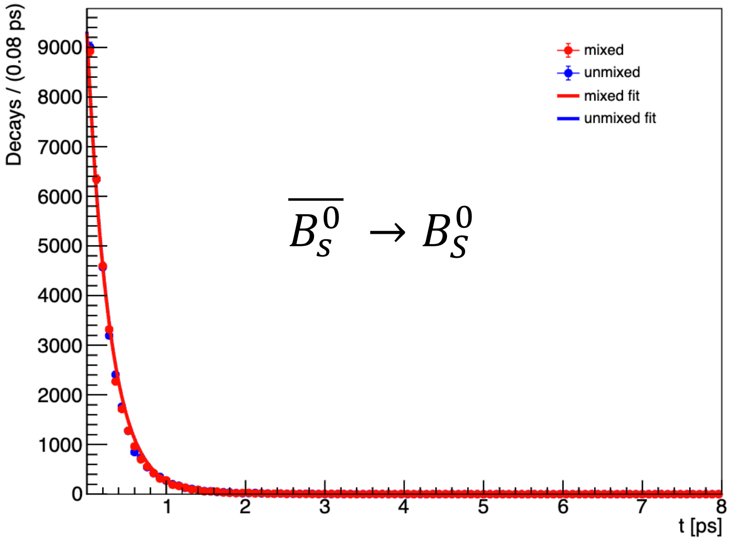
e.g. mix: $\overline{B_s^0} \rightarrow B_s^0 \rightarrow D_s^- \pi^+$ $unmix$: $B_s^0 \rightarrow B_s^0 \rightarrow D_s^- \pi^+$

creation time: t1 t2 t3

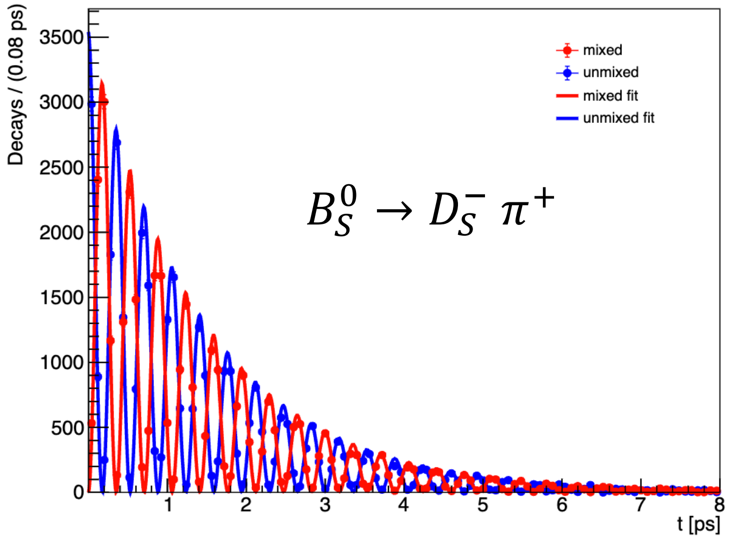
t3-t1



t2-t1



t3-t2

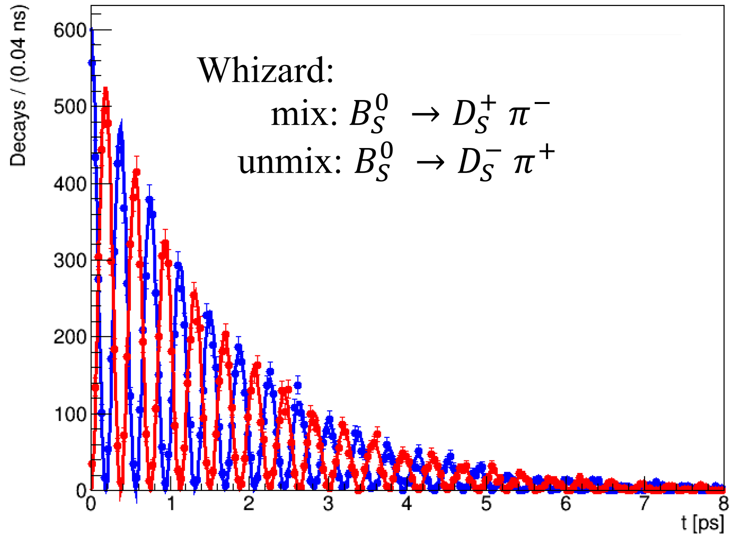


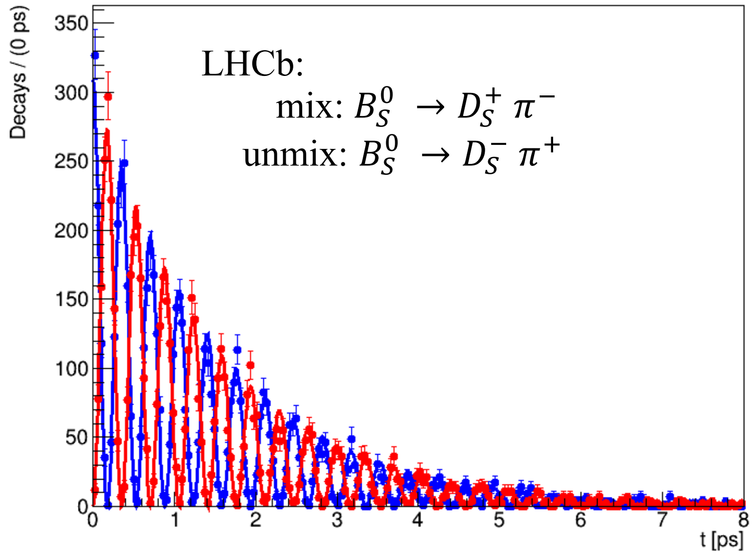
Source	PDG	LHCb simulation	Herwig output(t3-t1)	t3-t2
$\Gamma_s(\mathrm{ps}^{-1})$	0.66	0.65	0.717	0.679
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.085	0.162	0.353	0.159
$\Delta m_s(\mathrm{ps}^{-1})$	17.7683	17.806	17.752	17.789

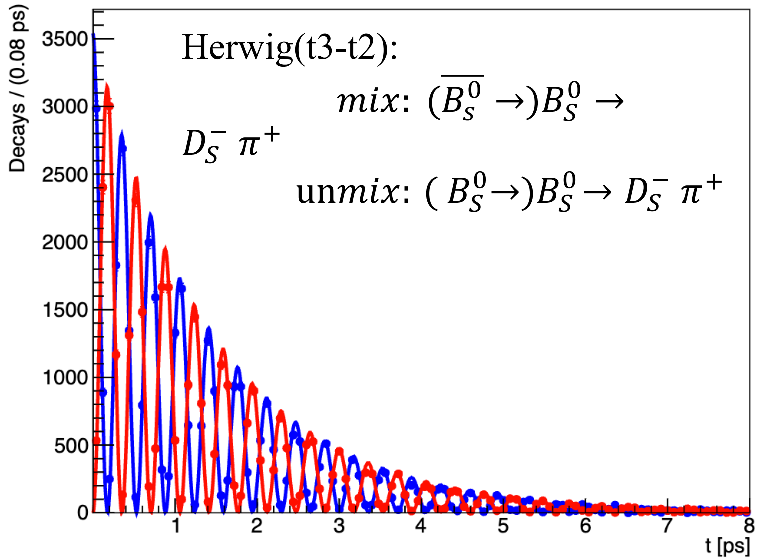
Bs Oscillation in samples

1. Compare Bs oscillation in three sources, LHCb and Whizard give the same decay model, also ‘t3-t2’ in Herwig.

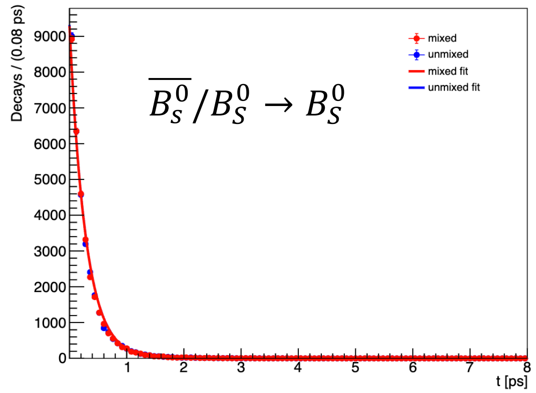
Source	PDG	LHCb simulation	Herwig output(t3-t1)	t3-t2	new Whizard output
$\Gamma_s(\mathrm{ps}^{-1})$	0.66	0.65	0.717	0.679	0.64
$\Delta\Gamma_s(\mathrm{ps}^{-1})$	0.085	0.162	0.353	0.159	0.235
$\Delta m_s(\mathrm{ps}^{-1})$	17.7683	17.806	17.752	17.789	16.694







t3-t2 have the same oscillation as LHCb simulation, because they both use EvtGen.



Discussion with Herwig:

1. If ‘t2-t1’ is no sense here.
2. Update the EvtGen interface.

Bs Oscillation in Herwig update

1. First input B mixing in Herwig2.5(2001), controlled by Herwig itself.
2. Evtgen took over to be used for a simulation of B-hadron decays from Herwig7.1
3. What we used to produce large samples is Herwig7.2.
4. B mixing update didn't be metioned in the least Herwig7.3 release note.
5. But they promised to update in Herwig7.3 release note, which published in 2008…

Herwig++ has been extended enormously since the last version for which a published manual exists, 1.0. It now provides complete simulation of hadron–hadron collisions with a new coherent branching parton shower algorithm, including quark mass effects, a sophisticated treatment of BSM interactions and new particle production and decay, an eikonal model for multiple partonic scattering, greatly improved secondary decays of hadrons and tau leptons and a set of input parameters that describe e^+e^- annihilation data rather well.

New features planned for the near future include: an improved treatment of baryon decays; spin correlations within the parton shower; 'multiscale' showering of unstable particles; simulation of DIS processes; B mixing; and an improved treatment of gluon splitting to heavy quarks. Of course we are all users of Herwig++ as well as developers and are working on a large number of other new features related to phenemenological studies we are making. The list will continue to grow, according to the physics interest and needs of ourselves and others using it for physics studies.

In many aspects, the physics simulation included in Herwig++ is already superior to that in the FORTRAN HERWIG and our intention is that with the features just listed, the next major version release of Herwig++ will replace HERWIG as *the* recommended product for simulating hadron emission reactions with interfering gluons.