# $\Upsilon(4S) \rightarrow \Upsilon(1S)$ *Inclusive*

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## Contents



## 1 Introduction

We are interested in looking at the inclusive decay modes of $\Upsilon(4S) \rightarrow \Upsilon(1S) + \pi\pi, \eta, \eta^{'}$ where $\Upsilon(1S) \rightarrow \mu^{+}\mu^{-}$. We want to measure the branching fractions of these inclusive decays and see if the sum of the exclusive branching fractions can be saturated by this measurement.

## 2 Systematics

For this branching fraction measurement, we will use the equation

$$BR = \frac{N(\Upsilon(1S)_{4S}) - N(\Upsilon(1S)_{off-res})/c}{\epsilon \times N(\Upsilon(4S))} \tag{1}$$

where, for the variables, we have:

| | |
|---|---|
| $N(\Upsilon(1S)_{4S})$ - | From fit to $\Upsilon(1S)$ mass peak for on-resonance data |
| $N(\Upsilon(1S)_{off-res})$ - | From fit to $\Upsilon(1S)$ mass peak for off-resonance data |
| c - | Correction factor for ISR production (taken from literature, cross check with PHOKHARA) |
| $\epsilon =$ | $\epsilon_{sig} \times \epsilon_{trig}$ ($\epsilon_{sig}$ - Signal Efficiency; $\epsilon_{trig}$ - Trigger Efficiency) |
| $N(\Upsilon(4S))$ - | Taken from B-counting measurement |

## 2.1 Selection Criteria

The selection criteria for events from MC and off-resonance data include:

- thetaInCDCAcceptance
- dr $< 0.5$ & $|dz| < 2$
- muonID $> 0.25$

## 2.2 Signal Efficiency

From a sample of a million total generated events, the number of events of $\Upsilon(1S) \to \mu^+\mu^-$ reconstructed from truth matching from the decay modes

$$\begin{aligned} \Upsilon(4S) &\to \Upsilon(1S) + \pi^+\pi^- \\ &\to \Upsilon(1S) + \pi^0\pi^0\ [\pi^0 \to \gamma\gamma] \\ &\to \Upsilon(1S) + \eta \end{aligned}$$

would yield a signal efficiency of

$$\epsilon_{sig} = \frac{N(rec)}{N(gen)} = \frac{772707}{1000000} \approx 77\ \%.$$

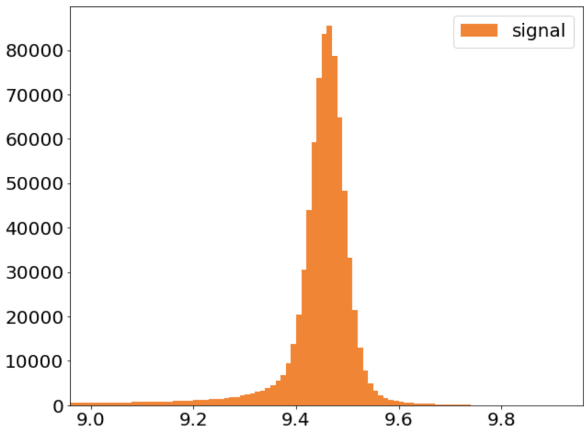


Figure 1: $\Upsilon(1S)$ Invariant Mass

### 2.2.1 Additional Decays

To check the validity of the signal efficiency value of the $\Upsilon(1S)$ invariant mass, additional decay modes were investigated. The additional modes were $\Upsilon(4S) \to \gamma X_b(2P) \to \gamma\Upsilon(1S)$ and $\Upsilon(4S) \to \Upsilon(1S) + \eta'$. From these decay modes, the recoil mass squared ($M^2_{recoil}$) was investigated to see if similar values to the signal efficiency were found. Out of 10,000 total generated events, the number of events for $M^2_{recoil}$ were 7857 and 8085 for the above decays, respectively. In percent, these values are, approximately, 78 % and 80 % and are comparable to the value found for the signal efficiency.

## 2.3 Trigger Efficiency

In this study, we use the ffo trigger line because we want to select the trigger line that is most sensitive to the di-muon decay channel since we looking at the inclusive decays of $\Upsilon(4S) \to \Upsilon(1S) + \pi\pi, \eta, \eta^{'}$ with $\Upsilon(1S) \to \mu^+\mu^-$. To understand the efficiency of using the ffo trigger line, we investigate the ffo track trigger cut efficiency using the decay mode $e^+e^- \to \gamma_{ISR}\mu^+\mu^-$ in continuum.

By asking for the events that pass the ffo trigger, a good estimate of the efficiency can be found since the photon in the acceptance will allow for the rejection of all other processes but the process including the ISR photon. In addition to this, selecting the mass in the $\Upsilon(1S)$ upper sidebands will give no $\Upsilon$ contamination.

From the decay $e^+e^- \to \gamma_{ISR}\mu^+\mu^-$ in the off-resonance data (buckets 12 and 15) and applying the selection criteria from above in addition to hie and ffo track trigger cuts, the trigger efficiency was found to be

$$\epsilon_{trig} = \frac{N(ffo\&hie)}{N(hie)} = \frac{130980}{170372} = 76.878\ \%.$$

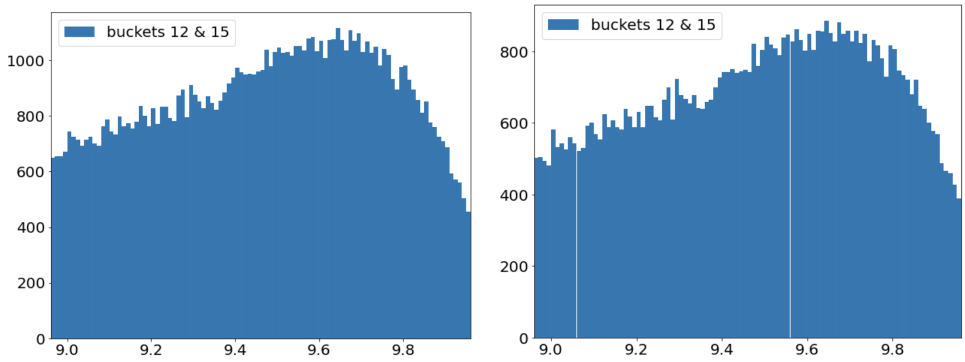


Figure 2: $\Upsilon(1S)$ Invariant Mass before (left) and after (right) ffo track trigger cut applied.

## 2.4 Number of $\Upsilon(1S)$ (off-resonance)

Fitting to the $\Upsilon(1S)$ invariant mass peak in the off-resonance data (buckets 12 and 15) and applying the selection criteria from above in addition to the ffo track trigger cut, the

number of events yielded are 3027 from a background of 366200.

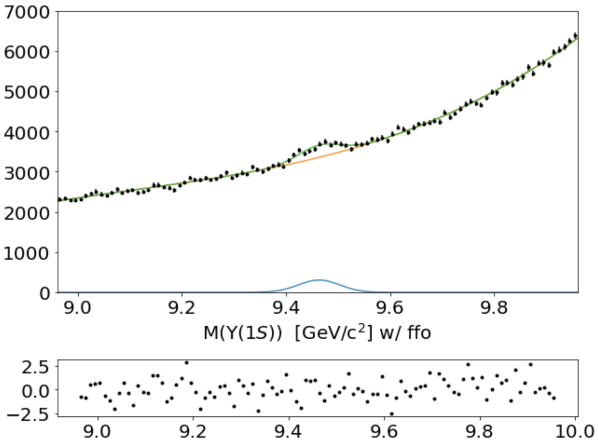


Figure 3: Fit to $\Upsilon(1S)$ Invariant Mass with Pull Distribution