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# Feasibility study on cross-section measurement of $\Upsilon(1S)\rightarrow\mu^+\mu^-$ by using early CMS data*

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**Abstract** One of the first physics results that CMS will hopefully obtain will be the analysis of heavy quarkonium productions, including the $\Upsilon$ cross-section measurement. Since the $\Upsilon$ production cross-section from p-p collisions is expected to be relatively large, the analysis should be viable with rather small datasets which will be available soon after the start-up of the LHC. This paper describes the methods and plans for measuring the differential cross-section of $\Upsilon(1S)\rightarrow\mu^+\mu^-$ production, by using data to be collected from the CMS detector in the first LHC run. In this study, about 80 thousand $\Upsilon$ are reconstructed corresponding to an integrated luminosity of 6.4 $pb^{-1}$ in 10 TeV proton-proton collisions by using Monte Carlo data. The precision of this measurement is estimated to be about 16%, which is limited by the systematic errors.

**Key words** LHC, CMS, upsilon mesons, cross-section

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## 1 Introduction

The Large Hadron Collider (LHC) [1] will be the most powerful scientific instrument in the world for particle physics research at the unprecedented proton-proton collision energy of 7×7 TeV and the luminosity of $10^{34}$ $cm^{-2}\cdot s^{-1}$. When LHC is switched on, it will produce heavy quarkonium mesons in abundance, even at the lower collision energy of 5×5 TeV (in the first year) and a much lower (than the designed) luminosity during the first few years of its running. These heavy quarkonium mesons can be readily detected and analysed by the CMS (Compact Muon Solenoid) experiment, which is one of the two general purpose experiments on LHC and has been described in detail elsewhere [2]. CMS emphasizes the muon measurement with high resolution, as it embeds the “Muon” in its name. The study presented in this paper is just for the $\Upsilon$ mesons reconstructed from its muon decay products.

The reasonable branching fraction of the $\Upsilon$ decaying into di-muon pairs is helpful for the relatively easy separation of these events from the huge amount of hadronic background at the LHC. Also, the studies of heavy quarkonium in CMS experiments with the early data (in a short period) can probe the region of higher transverse momentum than is feasible in CDF and D0 experiments on Tevatron at Fermilab, so it will help to verify the predictions of various theoretical models.

Since the discovery of the heavy quarkonium mesons a few decades ago, they have been studied extensively. However, still some puzzling problems remain, e.g. their underlying production mechanism in hadron collisions. Heavy quarkonium production is reviewed in Ref. [3]. There has been a “well-known” discrepancy (as much as a couple of orders of magnitude) in the quarkonium production cross-section between the results of CDF experiments on Fermilab’s Tevatron in 1990’s and some theoretical predictions (e.g. by the leading order Colour Singlet Model (CSM)). Later, the Non-Relativistic QCD (NRQCD), including the Colour Octet Mechanism (COM), which allows production at the parton level also to occur through a colour octet quark pair, should eventually fit the experimental transverse momentum spectra of

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quarkonium production cross-sections. However, the prediction of COM that the polarization of prompt heavy quarkonium will be transverse has disagreed with the experimental data (e.g. the recent results [4] from CDF and D0 experiments show an opposite trend in the meson's polarization).

Facing this contradiction between the theory and experimental results, re-measurement of the cross-section and the polarization of heavy quarkonium in CMS experiments may help to solve this puzzle, since it can collect larger events samples of heavy quarkonium at higher transverse momentum and with wider coverage of pseudo-rapidity than the CDF and D0 experiments, even in the early stage of the LHC's first run.

The differential cross-section and the polarization measurement for both J/ψ and Υ mesons can be used to test the heavy quarkonium production mechanism. Compared with J/ψ, Υ has the advantage of lacking non-prompt components (i.e. the so-called B meson part) to contaminate the data sample of prompt heavy quarkonium, which there by reduces the complexity of the data analysis. Another advantage of Υ is the lower speed due to its larger mass, which makes it more non-relativistic and more suitable for testing the NRQCD theory. However, since the cross-section of Υ production is about one order of magnitude smaller than that of J/ψs, the necessary statistics take longer to gather.

This paper mainly describes the procedure for measuring the $\Upsilon(1S)$ differential cross-section by following the basic method mentioned in Ref. [5]. The cross-section of other resonances of Υ (e.g. $\Upsilon(2S)$ and $\Upsilon(3S)$, etc.) with CMS data will be studied and reported in other papers. In this article, the basic methods for measuring the $\Upsilon(1S)$ differential cross-section, including the data flow and the Monte-Carlo events data samples, are introduced in Section 2. The details in each step of this measurement, including the High Lever Trigger (HLT) and off-line reconstruction, are described in Sections 3 and 4. The Tag-and-Probe method is briefly explained to illustrate the reconstruction efficiency bias in Section 5. The estimations of systematic uncertainties are discussed in Section 6. The results and conclusion are given in Sections 7 and 8.

## 2 Data streams, data samples and analysis strategy

The heavy flavour quarkonium study consists of two steps. Firstly, the data are pre-selected by using a loose cut that requires the presence of a Υ, as selected by the HLT trigger (see Section 3.2). At this stage, a subset of events will be selected: skimmed requiring a single μ HLT trigger with the lowest $p_T^\mu$ (depending on which trigger menu will be available at different luminosities of LHC) and that will be used to measure the acceptance of Υ events. In the second step, the analysis continues to follow the off-line criteria to select the final data.

In this study, Monte-Carlo data events are used, which overall include about 100 thousand Υ and 475 thousand μ enriched minimum bias events. Both are processed by a full GEANT based detector simulation and pass through the standard CMS HLT and reconstruction program (called CMSSW, i.e. CMS simulation and reconstruction software package). In addition, about 17.4 million Υ events at generation level are produced for pre-selection study. The private background is generated and simulated by the Princeton group. Signal samples are generated and simulated with CMSSW_2_1_X, and re-digitized and re-reconstructed with CMSSW_2_2_X. To save CPU time, a filter (pre-selection) is added before the simulation step in the full chain MC process, requiring at least one $\Upsilon(1S)$ or $\Upsilon(2S\_1S)$ in one event and at least two μ with the opposite charge, both with $p_T^\mu > 2.5$ GeV/$c$ and $|\eta^\mu| < 2.5$, i.e. the μ will not be reconstructed in CMS until the above requirements are fulfilled. The other Monte Carlo samples in the analysis are also considered:

1) Background events. These should be considered, since the invariant mass of any other muon pair source could be close to the Υ mass accidentally. The sources of background events are: (1) the generic QCD 2→2 events produced with PYTHIA (MSEL=1), in which the presence of one μ with $p_T^\mu > 2.5$ GeV/$c$ and $|\eta^\mu| < 2.5$ is required, mainly coming from the heavy flavour quark decays. These events are referred to as the "μ enriched QCD background", hereafter; (2) the Dell-Yan process will also make a contribution to the background, but the influence of this part is so small that we only focus on the QCD background in this analysis.

2) Other resonance $\Upsilon(nS)$ events, including $\Upsilon(2S)$ and $\Upsilon(3S)$, etc. These will be used in the mass peak fitting process. In the real data measurement, the di-μ mass resonance spectrum will contain three peaks, and will be fitted by three double Gaussian functions. So, in our MC data study, all three peaks should be considered.

3) About 17.4 million Υ events at generation level without the pre-selection are used to study the pre-

selection rate and to describe the theoretical prediction regarding the cross-section.

The $\Upsilon$ differential cross section will be determined according to the formula

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}(\Upsilon)\cdot Br(\Upsilon\to\mu\mu)=\frac{N_{\Upsilon}^{\mathrm{fit}}}{\mathcal{L}\cdot A\cdot\Delta p_{\mathrm{T}}},$$

where $N_{\Upsilon}^{\mathrm{fit}}$ is the number of reconstructed $\Upsilon$ candidates in a given $p_{\mathrm{T}}$ bin. This is obtained by fitting the $\Upsilon$ mass spectrum with a linear background and double Gaussian signal hypothesis, to be explained in Section 3.1. $A$ is the total efficiency for pre-selecting, triggering and offline reconstructing the $\Upsilon$ events, as obtained from Monte-Carlo events, to be explained in Section 4. $\mathcal{L}$ is the integrated luminosity. $\Delta p_{\mathrm{T}}$ is the size of the $p_{\mathrm{T}}$ bin.

## 3 Υ events selection

In this study, CMSSW_2_1_12 is used for simulating the physics process occurring in the CMS detector. $\Upsilon$ candidates are reconstructed by pairing $\mu$ with at least 3.0 GeV/$c$ transverse momentum and with opposite charge. Since the background analysis is also introduced, the invariant mass of the $\mu$ pair is required to be between 9.0 and 10.0 GeV/$c^2$.

### 3.1 Υ mass spectrum

Since the mass mean and resolution are functions of $p_{\mathrm{T}}^{\Upsilon}$ and $|\eta^{\Upsilon}|$, one simple Gaussian function does not fit the $\Upsilon$ signal peak very well, while two Gaussian functions could do better. The di-muon mass spectrum including background and signal is given in Fig. 1. The level of the Drell-Yan background in the same mass window is estimated to be less than 1% with respect to the other background sources, so it is neglected hereafter. As explained in Section 2, the number of reconstructed $\Upsilon$ candidates in a given $p_{\mathrm{T}}$ bin is obtained by fitting the $\Upsilon(nS)$ mass spectrum with a linear background and three double-Gaussian signal hypothesis. The background invariant mass distribution could be described by a linear function well.

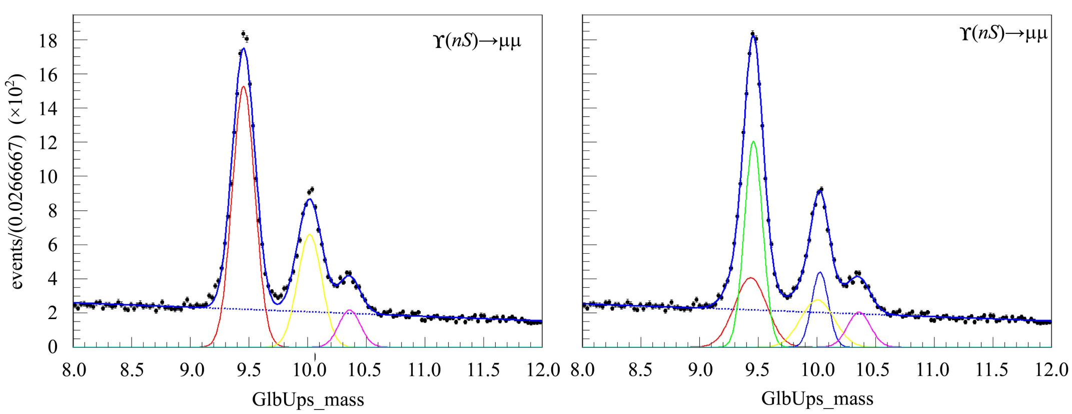


Fig. 1. Di-muon invariant mass distribution, i.e. $\Upsilon$ signal plus QCD background in linear scale, is fitted with a linear function (dashed line) plus three single Gaussians (corresponding to the 3 peaks at $1S+2S\_1S$, $2S$ and $3S$) in the whole $p_{\mathrm{T}}^{\Upsilon}$ range (left). The same but with the signal fitted with three double-Gaussian functions as shown below the data dots (right).

### 3.2 Υ trigger selection

Since the $\Upsilon\to\mu\mu$ channel is an excellent source for the detector calibration and alignment at the earlier runs of CMS, the HLT trigger group would like to accumulate as many $\Upsilon\to\mu\mu$ samples as possible. Under the luminosity of around $10^{30}$ cm$^{-2}\cdot$s$^{-1}$, CMS is expected to collect about 200 pb$^{-1}$ data in the first run period of LHC. There will be more information about the CMS trigger system in the Trigger menu list [6] and in the CMS Physics Technical Design Report [7].

The CMS trigger system consists of Level-1 (L1), Level-2 (L2) and Level-3 (L3). At L1, L1_DoubleMu3 trigger is used. The primary filter condition is a double $\mu$ trigger with $p_{\mathrm{T}}^{\mu}>3$ GeV/$c$. L1 $\mu$ candidates are then used to seed the reconstruction of L2 $\mu$ in the muon chambers. At L2, $\mu$ candidates are reconstructed after passing the filter for $\Upsilon$: at least two L2 $\mu$ with opposite charge, $p_{\mathrm{T}}^{\mu}>3$ GeV/$c$, the invariant mass of this di-muon pair is between 6.0 and 13.0 GeV/$c^2$. The $\Upsilon$ resonance is refined by this large mass window. Due to the poorer momentum resolution of the L2 $\mu$, the invariant mass of the L2 $\mu$ pair has a width of 898 MeV/$c^2$, which is about one order of magnitude larger than that of L3. At L3, the tracker information is combined with the information from the muon chambers to determine L3 μ, by constraining the L2 μ to the interaction region defined in a η-ϕ region. The L3 ϒ filter requires at least two L3 μ with opposite charge and $p_T^{\mu} > 3$ GeV/$c$, and their invariant mass ranges from 8.0 to 11.0 GeV/$c^2$.

## 4 Total acceptance *A*

The total efficiency $A$ contains three parts: the pre-selection rate, the trigger efficiency and the offline reconstruction efficiency. Actually, in the cross-section measurement, the efficiency will be evaluated by using the Monte-Carlo data first. It should eventually be cross-checked by real experimental data in the CMS detector with the Tag-and-Probe technique, which is discussed in Section 5.

### 4.1 The offline reconstruction efficiency

The μ candidates are reconstructed and identified with the GlobalMuonProducer algorithm in CMSSW. This algorithm makes use of both the muon chambers and the silicon tracker. First of all, a segment is found in the muon stations, which is then matched to a compatible track in the silicon tracker before a combined trajectory is fitted, yielding a global reconstructed muon track. The CMS detector could offer the $\eta$-coverage range $|\eta^{\mu}| < 2.4$ for μ reconstruction. The performance of single μ reconstruction covers the range $p_T^{\mu}$=10–1000 GeV/$c$, but μ decayed from ϒ generally have lower $p_T^{\mu}$.

The single μ reconstruction efficiencies as a function of $p_T^{\mu}$ and $\eta^{\mu}$ are shown in Fig. 2. Most of the μ with $p_T^{\mu} < 4$ GeV/$c$ cannot reach the barrel muon chambers (corresponding to the region of $|\eta| < 1.2$), so the efficiencies are lower in this region. The efficiency drops around several pseudorapidity values, e.g. $|\eta^{\mu}|$=0.25 and 0.75 (where there are hardware gaps inside the barrel muon system), $|\eta^{\mu}|$=1.2 (where the barrel and endcap muon systems overlap), and $|\eta^{\mu}|$=1.7–1.8 (where there are hardware gaps inside the endcap muon system). The maximum efficiency (about 95%) is reached for $p_T^{\mu} > 7$ GeV/$c$, for all $\eta^{\mu}$.

It is estimated that the μ fake rate is about 0.3%. A fake μ mainly comes from the decay of $\pi^{\pm}$ or $K^{\pm}$ before reaching the muon chambers. As a result, the majority of these decayed μ are reconstructed as the fake μ.

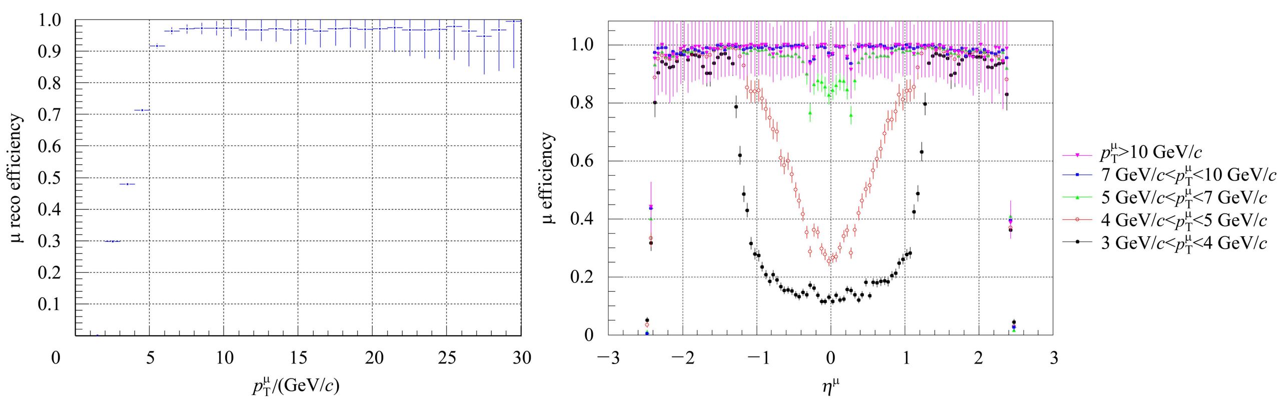


Fig. 2. μ reconstruction efficiency vs. $p_T^{\mu}$ with $|\eta^{\mu}|$<2.5 (left) and vs. $\eta^{\mu}$ at different $p_T^{\mu}$ (right).

### 4.2 ϒ acceptance

As mentioned before, ϒ candidates are reconstructed by pairing μ with $p_T^{\mu} > 3.0$ GeV/$c$ and opposite charge. The invariant mass of the μ pair is required to be between 9.0 and 10.0 GeV/$c^2$. Furthermore, the two μ from a common vertex are required, which is determined by the point of their closest approach in space with the Kalman Vertex Fitter. It should be noted that the efficiency of this vertex requirement in the Monte Carlo sample is 0.9996±0.0001.

In CMS, μ could be detected once satisfying the condition that $p_T^{\mu}$ >3.0 GeV/$c$ and $|\eta^{\mu}|$ <2.5. Otherwise, it cannot reach the muon chambers, i.e. cannot be detected as a global μ. Thus, one $\Upsilon \to \mu\mu$ event should also include at least two μ with the same conditions. So, in the Monte Carlo simulation, a generator di-muon filter (pre-selection) is applied before the simulation process in order to save the CPU time.

Distribution of this acceptance is shown in Fig. 3. This efficiency decreases along the increasing $p_T^{\Upsilon}$ and reaches a minimum at about $p_T^{\Upsilon}$ ~5 GeV/$c$. There are also some factors that affect the efficiency measurement, e.g. the misalignment of CMS, the influence of polarization, etc. All these effects will be studied as systematic uncertainties in Section 6.

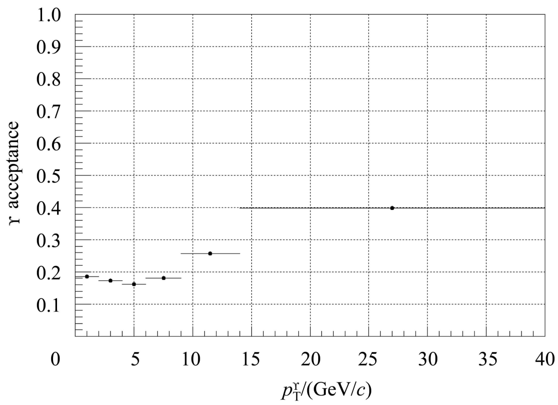


Fig. 3. The distribution of $\Upsilon$ acceptance.

## 5 Reconstruction efficiency bias

The possible bias and degradations in efficiency study have been investigated. In this analysis, data based efficiency calculation (the so-called Tag-and-Probe methodology) is brought into the cross-section measurements. Tag-and-Probe methodology is a useful tool to measure the reconstruction efficiency of a particle (a muon in this case) decayed from the source with a known resonance (e.g. J/ψ, $\Upsilon$ or Z). Since the data driven measurement will not use any information at the generator level, it could be of great help in the improvement of Monte Carlo simulation, especially at the beginning of an experiment. In this paper, the "Tag" should be a muon reconstructed in CMS with very good quality, so the global muon

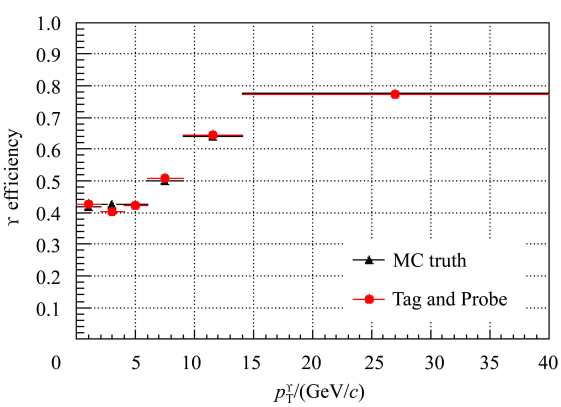


Fig. 4. Global $\Upsilon$ reconstruction efficiency vs. $p_T^\Upsilon$, based on the Monte Carlo truth (triangles) and the Tag-and-Probe method (circles).

is chosen. The "Probe" is all possible tracks reconstructed in tracker sub-detector. One "Tag" and one "Probe" could be considered as a mother particle candidate with a known invariant mass. Thus, the particular track and muon could be selected and the efficiency of the muon and $\Upsilon$ could be calculated. Differences between the MC based efficiency and the data based Tag-and-Probe efficiency (shown in Fig. 4) will be taken into account in the systematic uncertainties. Apparently, the difference is not too great. The detailed Tag-and-Probe methodology will be introduced in another paper.

## 6 Systematic uncertainties

Based on the factors in the formula given in Section 2, possible systematic uncertainties are estimated. Some of the systematic errors come from the other's study, e.g. the estimations of the uncertainties of the luminosity or the polarization. All the estimations in this section are achieved by MC data analysis. When the LHC is switched on and real experiment data are collected, some of the systematic uncertainties could be evaluated more exactly, e.g. the luminosity determination and the bias to the offline reconstruction efficiencies, as explained in Section 5, etc. The possible systematic uncertainties that have been considered are:

1) Luminosity determination. The CMS Luminosity Group will provide the real time monitoring of the LHC performance and the overall normalization to physics analysis. When LHC is running, the online luminosity will be measured and its uncertainty determined. At this stage before the LHC re-starts, the luminosity uncertainty is estimated to be in the order of 10% or less [8]. As a comparison, the uncertainty of CDF Ⅱ is about 5.9%, corresponding to an integrated luminosity of 39.7 $\text{pb}^{-1}$ [9]. However, since there are no real experimental data yet, this uncertainty is conservatively estimated to be 10% in this study.

2) Muon momentum scale. As explained in Section 4, one $\Upsilon$ sample is reconstructed from a di-muon pair, and the momentum scale of the two μ influences the mass of the di-muon pair linearly. The number of $\Upsilon$ events in a given $p_T^\Upsilon$ bin will be fitted from the di-muon invariant mass spectrum by a double Gaussian function. Thus, the number under the double Gaussian peak could be affected by the difference in the muon $p_T^\mu$ cut between the reconstructed data and the Monte Carlo input. This uncertainty in the muon momentum scale is estimated to be at most 1%.

3) The mass fitting function. As explained in Section 3.1, a double Gaussian function is used to nicely

fit the invariant mass spectrum to describe the number of $\Upsilon$ events in the given $p_{\rm T}^{\Upsilon}$ bin. To determine the uncertainty of this double Gaussian function fit, these samples are re-fitted by a single Gaussian. The differences among these three numbers (the one extracted from the double Gaussian function, the single Gaussian, and the input value) in each $p_{\rm T}^{\Upsilon}$ bin will be obtained by,

$$\mathrm{Max}\left(\left|N^{\rm double}-N^{\rm single}\right|,\left|N^{\rm double}-N^{\rm input}\right|\right),$$

and the parameterization brings the uncertainty to an order of 5%. Once large data samples are available, the events in each bin will be split into three separate $|\eta^{\Upsilon}|$ regions with the following boundaries: (0.0–0.8–1.6–2.4), to test the influence of $\eta^{\Upsilon}$. However, the statistic of $\Upsilon$ samples in this study is not so large to form a new peak in some of these separate $|\eta^{\Upsilon}|$ regions. This could be managed in the real data analysis, since there will be many more events then.

4) Binning in $p_{\rm T}^{\Upsilon}$. The basic principle of the choice of binning in $p_{\rm T}^{\Upsilon}$ is to attain enough samples to form a peak in this $p_{\rm T}^{\Upsilon}$ range. Hence larger binning is chosen to allow for enough signal and background statistics in the higher $p_{\rm T}^{\Upsilon}$ region. The binning affects the total efficiency $A$ as a function of $p_{\rm T}^{\Upsilon}$ bin. $\Delta A/A$ is defined as a systematic uncertainty from the binning in $p_{\rm T}^{\Upsilon}$, where

$$\Delta A=\frac{1}{4}\sum_{i=1}^{4}A_i-\frac{\sum_{i=1}^{4}A_iN_i}{\sum_{i=1}^{4}N_i}.$$

This means that the total acceptance $A$ is recalculated in four smaller bins split from the former $p_{\rm T}^{\Upsilon}$ bin equally. The relative difference between the average of $A$ in every four sub-bins and the former $A$ is considered as the uncertainties of binning in $p_{\rm T}^{\Upsilon}$ on the total acceptance.

5) Finite Monte Carlo statistics. The systematic uncertainty contributed by the pre-selection rates is considered to be the MC statistics.

6) $\Upsilon$ polarization. The influence of $\Upsilon$ polarization on the total acceptance as a function of $p_{\rm T}^{\Upsilon}$ is shown in Fig. 5. The total acceptance varies from $-0.15\%$ to $+40\%$ for the extreme cases of either purely transverse or longitudinal polarizations. The next step after this cross-section measurement is to study the polarization with both MC and collision data in CMS. In the absence of this currently, here the systematic uncertainty is estimated from the polarization measurement of CDF for $\Upsilon$ [10], where the largest polarization parameter $|\alpha|$ is measured to be 0.12. Thus, the systematic uncertainty is estimated by varying the polarization parameter $\alpha=\pm0.15$ as the standard deviations around the measured value. The uncertainty is found to be 2.4% near $p_{\rm T}^{\Upsilon}$=6 GeV/$c$ and 3.7% in the region $p_{\rm T}^{\Upsilon}>20$ GeV/$c$.

7) The bias to the total efficiency. This bias in efficiency between MC truth and data (the Tag-and-Probe technique) is considered to be the uncertainty, which is evaluated to be 5%, as shown in Section 5.

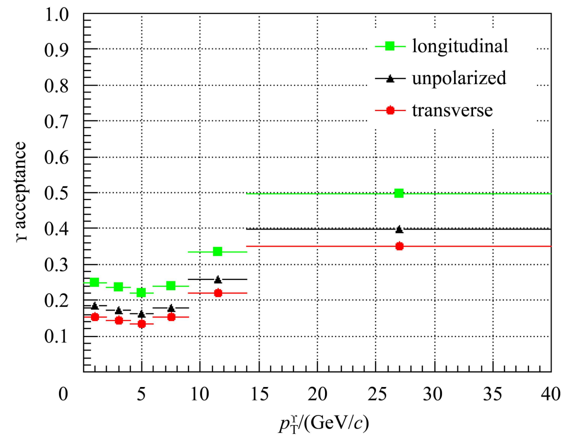


Fig. 5. $\Upsilon$ total acceptance as a function of $p_{\rm T}^{\Upsilon}$: transverse polarization (lower-dot), longitudinal polarization (upper-square) and non-polarized production (middle-triangle).

Table 1. Summary of possible systematic uncertainties in the $\Upsilon$ cross-section measurement with MC data. The total efficiency is about 11% in the high $p_{\rm T}$ range and 21% at the $p_{\rm T}$ bin 8–9 GeV/$c$.

| Parameter affected | Source | $\Delta\sigma/\sigma$ |
|---|---|---|
| Luminosity | Luminosity | ∼10% |
| Number of $\Upsilon$ events | Momentum scale | ∼2% |
| | $\Upsilon$ mass fit | 1.1% – 2.6% |
| | Data quality | ∼1% |
| Total acceptance | Polarization | 0.5% – 3.7% |
| | $p_{\rm T}$ spectrum | 0.1% – 2.0% |
| | MC statistics | 0.3% – 3.9% |
| | Efficiency bias | 0.3% – 5.3% |
| Total | 11.4% – 21.3% | |

## 7 Results

The result of this study shown in Table 2 displays the values of the $\Upsilon$ cross-section with systematic and statistical uncertainties.

This result illustrates that the $\Upsilon$ differential cross-section could be measured under an integrated luminosity of 6.4 pb$^{-1}$ based on MC data. Fig. 6 displays it with combined systematic and statistical uncertainties. From Table 2, it can be seen that there is good agreement between MC input values and the number calculated. The low level of background and the ideal performance of reconstruction lead to systematic uncertainties with precision of around the level of 16%. It is expected that the first run of LHC could produce about 200 $\text{pb}^{-1}$ experimental data. So the measurement based on real experimental data should be much better in statistics and can limit the systematic uncertainties. The most important improvements (compared with CDF) are at the higher $p_T$ and with the larger $\eta$ range coverage. The real experimental data will be used to cross check the efficiencies, i.e. to re-calculate the efficiencies by the Tag-and-Probe method.

Table 2. Summary of the $\Upsilon$ cross section as a function of $p_T^\Upsilon$ with statistical and systematic uncertainties.

| $p_T^\Upsilon$ bin/(GeV/$c$) | $\text{d}\sigma/\text{d}p_T\cdot Br(\Upsilon\to\mu\mu)$/(nb/(GeV/$c$)) | MC input values/(nb/(GeV/$c$)) |
|---|---|---|
| 0∼1 | 1.353±0.042(stat)±0.170(syst) | 1.356 |
| 1∼2 | 3.426±0.106±0.432 | 3.521 |
| 2∼3 | 4.665±0.144±0.600 | 4.867 |
| 3∼4 | 5.022±0.155±0.724 | 5.143 |
| 4∼5 | 4.470±0.138±0.735 | 4.604 |
| 5∼6 | 3.669±0.113±0.686 | 3.758 |
| 6∼7 | 2.892±0.089±0.528 | 2.928 |
| 7∼8 | 2.179±0.067±0.424 | 2.226 |
| 8∼9 | 1.618±0.050±0.345 | 1.673 |
| 9∼10 | 1.223±0.038±0.223 | 1.252 |
| 10∼11 | 0.9492±0.0302±0.1895 | 0.9381 |
| 11∼12 | 0.6951±0.0225±0.0966 | 0.7061 |
| 12∼13 | 0.5177±0.0171±0.1005 | 0.5405 |
| 13∼15 | 0.3569±0.0116±0.0546 | 0.3633 |
| 15∼17 | 0.1972±0.0066±0.0253 | 0.2164 |
| 17∼19 | 0.1238±0.0043±0.0197 | 0.1334 |
| 19∼21 | 0.08062±0.00288±0.01135 | 0.08520 |
| 21∼24 | 0.05047±0.00178±0.00851 | 0.05003 |
| 24∼28 | 0.02492±0.00092±0.00329 | 0.02517 |
| 28∼34 | 0.009790±0.000391±0.001294 | 0.01066 |
| 34∼40 | 0.003824±0.000194±0.000544 | 0.004233 |

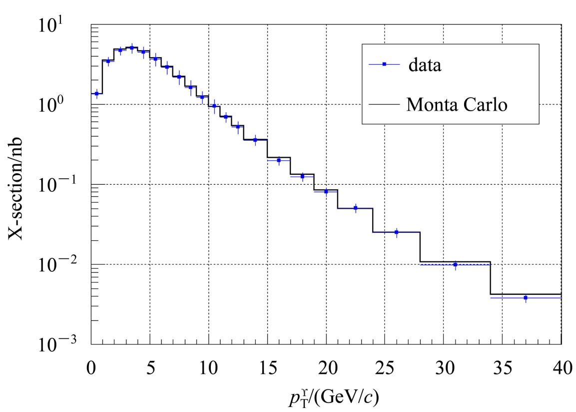


Fig. 6. The inclusive $\Upsilon$ differential cross-section as a function of $p_T^\Upsilon$, corresponding to an integrated luminosity of 6.4 $\text{pb}^{-1}$.

## 8 Conclusion

In this paper, a feasibility study for the $\Upsilon(1S)$ differential cross-section measurement is described. Under the di-muon decay channel, about 6.4 $\text{pb}^{-1}$ data samples are produced in CMSSW.

As listed in Table 2, the uncertainties of this study are mainly systematic. It is expected that the real experimental data with larger integrated luminosity could limit not only the statistic uncertainties but also the systematic. For instance, the uncertainties from background fit could be depressed under the large statistic, the uncertainties from efficiencies bias could also be limited by using the Tag-and-Probe method, and the uncertainties from the polarization should be reduced once the polarization measurement is performed with more data. This analysis may also help with detector alignment.

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## References

1 Evans L, Bryant P. Journal of Instrumentation, 2008, **3**: S08001
2 Chatrchyan S et al (CMS collaboration). Journal of Instrumentation, 2008, **3**: S08004
3 Lansberg J P. International Journal of Modern Physics A, 2006, **21(19&20)**: 3857
4 The D0 collaboration. D0 Note 5089-conf
5 YANG Z, QIAN S. Chinese Physics C, 2009, **33**(8): 609
6 https://twiki.cern.ch/twiki/bin/view/CMS/TriggerTables
7 CMS collaboration. Physics Technical Design Report Vol. I, Chapter 9. CERN/LHCC 2006-021, 2006
8 https://twiki.cern.ch/twiki/bin/view/CMS/LumiWikiHome
9 CDF collaboration. Phys. Rev. D, 2005, **71**: 032001
10 CDF collaboration. Phys. Rev. Lett., 2002, **88**: 161802