Preliminary studies on $\Upsilon(1S)$ Visible/Invisible decays at the Belle II experiment, via γ_{ISR} procedure

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Abstract

Belle II represents the leading experiment at the high intensity frontier. The feasibility of the study concerning invisible decays of $\Upsilon(1S)$ is checked in the decay channel $e^+e^- \to \gamma_{ISR}\Upsilon(3S)$, $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to$ *invisible* , by means of the Belle II simulation framework. Visible decays of $\Upsilon(1S) \to \mu^+\mu^-$ from previous decay chain are used as control sample, to prove the consistency between pions kinematics in visible and invisible decays. Detector acceptance, reconstruction and total efficiency are provided to determine whether the Belle II experiment will be able to search for Dark Matter in invisible $\Upsilon(1S)$ decays, using the ISR technique.

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1 Introduction

The leading high-precision experiment Belle II represents its predecessor Belle upgrade, currently under construction in Tsubuka, Japan. It will be completed soon, ready for data-taking in 2017, together with the asymmetric energy accelerating facility SuperKEKB; its physics approach will be complementary to high-energy experiments, towards the high-intesity frontier.
Belle II ambition is not only to verify many Standard Model (SM) processes, such as CP violation in the B mesons sector, V_{CKM} matrix element measurement, but also to shade light on SM extensions by looking at processes in which Dark Matter (DM) could be involved. One of the examples to be taken into account is the invisible decay of $\Upsilon(1S)$ via γ_{ISR}, which is studied in this work: this is a newly-adopted technique, never used before since it requires high-luminosity experiments and dedicated trigger conditions. In order to determine the feasibility of this decay by using the γ_{ISR} procedure at the Belle II experiment, standard trigger conditions, already optimized for CP violation studies, are here tested and shown in detail. MonteCarlo simulations have been employed within the Belle II Analysis software; total efficiency is examined according to different requirements on the studied decay.

2 Motivation for Dark Matter search

The interest in the search for a new kind of matter arises from numerous astrophysical observations in the last 70 years, about its visible gravitational effects on ordinary matter in the Universe.
These last could be investigated in many ways, starting from the study of the stellar orbits inside galaxies, then going through the *gravitational lensing*, or even looking at the motion of hot clouds of gas inside clusters of galaxies. They all provide an estimation of the mass distribution inside galactic objects.
As a result, it was clear since the 1933 to F.Zwicky [1] that barionic matter could not explain itself the anomaly of galaxy rotational curves, and there should have been a huge amount of missing mass. Many theories have been developed and proposed to solve the contradictory experimental results, by means of introduction of extensions beyond the Standard Model of particle physics (BSM), since the latter does not allow any possible identification between particles and Dark Matter (DM) candidates. Among the most successful ones, the *SUSY* model has recently lost its supremacy, while theories that predict the existence of a *dark-sector* are spreading across the scientific community. Therefore, to be mentioned is the *Asymmetric Dark Matter* model, or so called ADM. Its name derives from the emphasis put on the observed asymmetry in the amount of DM over ordinary baryonic matter

(fig. 1), as seen by the PLANCK experiment for *Cosmic Microwave Background* radiation [2]:

$$\frac{\Omega_{DM}}{\Omega_{BM}} \sim 5.$$

where the parameter Ω represents the cosmologic abundance calculated at the value of critic density $\rho\, c$.
Typically, BSM theories, as well as ASM, resume in three adjectives the preminent DM candidate features: *cold* (non-relativistic), from the moment of its thermal production in the early universe; *dark*, because it does not interact electromagnetically; *stable* on cosmological scale, since its effects are still visible nowadays.
Moreover, some of these models predict the existence of a new light boson, called *dark photon* and belonging to an extra symmetry $\mathrm{U}(1)'$ [3, 4]. Calculations support the hypotesis of mixing of this new particle to ordinary SM photons. This way, it should be possible to open a portal to the dark sector [5], looking for example for any enhancement in the invisible decay channels of SM particles.

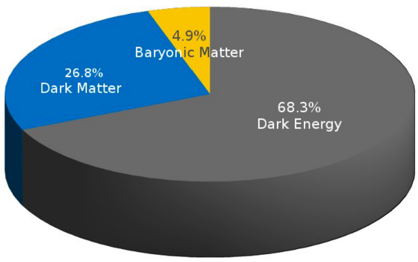


Figure 1: Representation of the relative abundances in our Universe: baryonic ordinary matter represent just a tiny 4.9%, if compared to the amount of Dark Matter ($\sim 26.8\%$) or Dark Energy ($\sim 68.3\%$), which is ultimately responsible for the acceleration process in the universe expansion [2].

2.1 Dark Matter detection

The irrefutable proof of DM existence has to be found in its interactions within the well-known SM sector. Depending on DM models, the scientific community is divided in three main fields of DM complementary research, corresponding to an equal number of developed detection techniques (fig. 2):

- **Direct search**: experiments seeking for elastic scattering of DM-target particles, looking at the recoil kinematics. Because it is supposed that a DM wind [6] is coming constantly from the centre of the Sun and our galaxy, then the aim is to build huge detectors, to increase the fiducial volume of interaction. Typical energy sensitivity should reach the order of 1-100 keV.

- **Indirect search**: the goal is to uncover any excess in the incoming flux of anti-matter, nuclei or neutrinos as they are produced by DM annihilation processes. Among the most successful experiments there are PAMELA and AMS02, that have recently confirmed an observed excess in the flux of positrons and anti-protons [7, 8].

- **Colliders**: the most interesting field of research, because it opens wide possibilities in the search for DM, since not affected by the astrophysical uncertainties. The intent is to discover new particles, looking at the *high energy frontier* (LHC) or either at the *high precision frontier* at the flavour-factories (Belle II) [9].

In the last few years, the interest in the flavour factories has been growing constantly: they represent the ideal environment where dark matter and dark forces could be discovered, enhancing the sensitivity to processes weakly coupled to SM, at a low energy level.

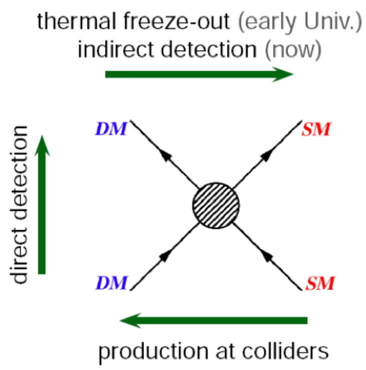


Figure 2: Illustration of the three DM detection techniques.

3 Belle II experimental overview

The present study has been developed within the Belle II DESY Group. All obtained results represent the product of MonteCarlo simulated events in the Belle II detector, located at the SuperKEKB facility [10] in the High Energy Accelerator Research Organization (KEK) in Tsubuka, Japan.

3.1 The accelerators: KEKB and SuperKEKB

The KEKB facility has been SuperKEKB progenitor [11]: this machine has been used as an asymmetric energy electron-positron accelerator.
Particles were injected from the source to different pre-accelerator machines, then delivered into the linear accelerator (LINAC) in order to reach their final collision energy, corresponding to $\Upsilon(4S)$ mass resonance. Finally, they were injected into two different 3 km long rings, called *High Energy Ring* (HER) for electrons and *Low Energy Ring* (LER) for positrons, respectively [12].
Collisions took place in the two beams crossing region, at an angle of ± 11 mrad and with an energy in the center of mass:

$$E_{cms} = 2\sqrt{E_{HER} \cdot E_{LER}} = 2\sqrt{8 \times 3.5}\,[GeV] = M_{\Upsilon(4S)} = 10.580\,GeV.$$

Beam asymmetry ensured a Lorentz boost in the center of mass of:

$$\beta\gamma = \frac{E_{HER} - E_{LER}}{E_{cms}} \simeq 0.42.$$

KEKB has been in activity from 1999 to 2010, when it has been proposed to increment its luminosity from $2.1 \cdot 10^{34}$ cm^2 s^{-1}, up to 40 times.
Its upgrade, named SuperKEKB [12] (fig. 3), will use a *nano-beam scheme*, in order to better collimate the beam in the vertical direction (up to 20 times of improvement); furthermore, the asymmetry between the energies of the two beams will be reduced, so to compensate the Thoushek effect [1] at high circulating current values. Selecting as final energies 4 GeV for the positrons and 7 GeV for the electrons, the Lorentz boost will be modified as well, reaching the final value of $\beta\gamma \simeq 0.28$.

3.2 The detectors: Belle and Belle II

The Belle detector is a large-solid-angle magnetic spectrometer and has been used during KEKB activity period [13]; it will be replaced by the new Belle II detector. Belle was located exactly around the beams interaction point, and its function was to provide very precise measurements on B mesons decays.
Moving from the innermost part to the outermost, several sub-detectors were arranged, so to fulfil different tasks. Belle core is made up of the Silicon Vertex Detector (SVD), used to determine very precisely the B mesons decay vertex position (crucial for CP-violation measurements) [14]. SVD is places inside the Central Drift Chamber (CDC), which is equipped with 50 detection layers and 8400

[1] This effect produces a loss of energy, due to coulombian scattering between the particles within the beam bunch.

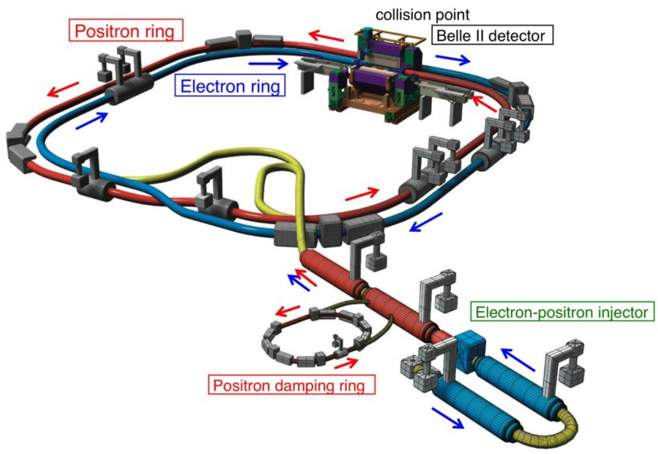


Figure 3: SuperKEKB layout illustration [12]. The figure shows the particle source, the linear accelerator (LINAC), the two storage rings and the Belle II detector, surrounding the beams collision point.

drift cells: measuring not only the tracks, but also their curvature inside the 1.5 T magnetic field and the particle energy deposit $-dE/dx$, momentum measurement and particle identification (PID) are provided. In addition, this last is also obtained thanks to the use of a more complex PID system: a set of two sub-detectors, namely an array of silica Aerogel Cherenkov Counters (ACC) and a Time of Flight counter (TOF). While the former provides an efficient means by which to separate between Kaons and Pions, the latter is used to measure the difference in time between the beams collision and the TOF layer crossing, which is more crucial for Photons identification. The PID complex is followed by the Electromagnetic Calorimeter (ECL), essential to distinguish electromagnetic cascades from hadronic ones. Showers shape and energy loss $-dE/dx$ in the CsI and BGO crystals have been used to accomplish this task. The Belle detector has been placed inside a Superconducting Solenoid (SC), providing a uniform magnetic field of 1.5 T ; its outermost part is represented by Resistive Plate Counters (RPCs) and some other sub-detectors, together called KLM system because separating Muons from Kaons. Since SuperKEKB is going to modify the luminosity and many other technical features, the Belle II detector design [15] has been changed as well, according to the new experiment needs (fig. 4). In order to reduce the beam-caused radiation damage and to increase precision in measurement techniques, the following substitutions have been introduced: most of the innermost sensors will be replaced by a new system of vertex Silicon Pixel Detectors (PXD); in addition to this, the newly built PID sub-detectors will be an Aerogel Ring Imaging CHerenkov (ARICH) and a Time Of Propagation (TOP). Furthermore, a completely new data acquisition system has been designed, so to get higher performances in the electronic readout. New plastic scintillators have been introduced in the KLM system, hence to reduce the amount of pile-up collisions due to high-rate background.

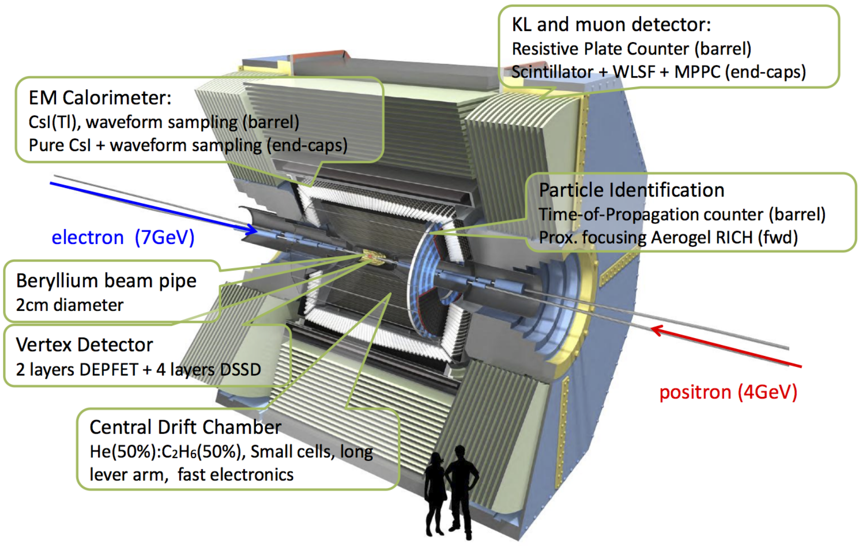


Figure 4: Belle II detector representation, together with comments to its most important components, from the innermost to the outermost part.

3.3 MonteCarlo event simulation and reconstruction in Belle II

MonteCarlo (MC) simulations produced for the present work have been developed within the Belle II Analysis Software (BASF2). Provided by the Belle II collaboration, this simulation framework is the result of an all-embracing dedication and effort.
The simulation and reconstruction procedure for the Belle II detector is conduced in three different steps:

1. Particle generation first step involves the combination of EvtGen [16] and Pythia [17] softwares, so as to produce as output a key file. This last contains all the most useful informations on the generation level: particles charge, PID number, four-momentum, decay probability and much more.

2. The Belle II detector geometry is then simulated by means of using the Geant4 [18] toolkit: particles produced in the previous step are then propagated inside the virtual detector, in order to look at its response to all the consequent interactions with its various materials, and also to estimate particles energy loss $-dE/dx$. Moreover, this step provides a detailed simulation of long-lived or unstable particles decays. As a result, an output file is generated, containing important information about the energy deposits inside the Belle II sensitive sub-detectors materials.

3. The last step, namely the event reconstruction procedure, involves more the BASF2 software, which is here used to read from the detector response output file. Hereafter, all particles tracks and decay vertexes are reconstructed, leading to a final ROOT [19] file which stores all useful variables to be further investigated for a complete physics analysis.

4 $\Upsilon(1S)$ invisible decays feasibility study

4.1 DM studies at Belle II

The current low-mass DM[2] search scenario is full of interesting underground experiments, pushing their detection limits and resolutions to incredibly low thresholds. The majority of them is moving towards the direct detection via cryogenic techniques. Hence they are looking for any scattering inside a huge liquid scintillator detector, that will be then converted into a signal hit.
However, many limits are intrinsic in their approach: despite the good performances, the irreducible background of neutrinos from the sun represents an insuperable barrier for their search and final estimation (fig. 5). On the other hand, parameter space fraction will be accessible to low energy collider experiments, such as Belle II, through the direct production of dark matter particles, e.g. from $\Upsilon(nS)$ decays. $\Upsilon(nS)$ is a bound state of a b quark and a $\bar{b}$ antiquark; the growing interest in its invisible decays arises from the allowed production in the phase space of two low mass DM particles, which might play a significant role [20, 21]. However, they are in general very much suppressed, since for instance:

$$\frac{BR(\Upsilon(1S) \to \nu\bar{\nu})}{BR(\Upsilon(1S) \to e^+e^-)} = \frac{27G^2 M^4_{\Upsilon(1S)}}{64\pi^2\alpha^2}(-1 + \frac{4}{3}\sin^2\theta_W)^2 \simeq 4.14 \times 10^{-4}.$$

[2] Low-mass dark matter is conventionally defined as DM with a mass value below 10 GeV/c^2

The purpose of this work is to examine the feasibility of the very suppressed decay:

$$\begin{aligned} e^+e^- &\rightarrow \gamma_{ISR}\Upsilon(3S), \\ \Upsilon(3S) &\rightarrow \pi^+\pi^-\Upsilon(1S), \\ \Upsilon(1S) &\rightarrow \chi\bar{\chi} \end{aligned} \tag{1}$$

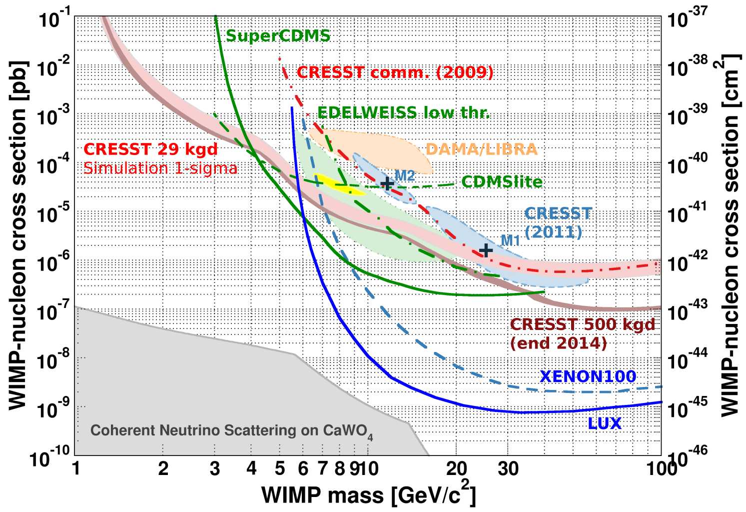


Figure 5: Exclusion plot regarding the current DM direct search limits, as they have been set up by cryogenic experiments. In the lower left corner, the irreducible background due to coherent neutrino scattering from the Sun is shown. The Belle II experiment will be able to access the region of DM mass below 5 GeV, without facing this limit, between $10^{-40} \div 10^{-45}$ cm^2.

at the Belle II experiment for the first time.
This procedure has never been adopted before, because other past experiments lacked sufficient luminosity to observe it. On the other hand, SuperKEKB, aiming to collect a record integrated luminosity of 50 ab^{-1}, would allow in principle any new rare-decay study like this one.
Indeed, looking at $\Upsilon(1S)$ invisible decays could be considered really challenging, unless focusing on the di-pion system kinematics: these two particles represent the best and the only resource to reconstruct the whole decay. Therefore, any signal would be seen as an excess of events in the recoil mass distribution (M$_{recoil}$), equivalent to the mass of the $\Upsilon(1S)$:

$$M^2_{recoil} = s + M^2_{\pi^+\pi^-} - 2E^{cms}_{\pi^+\pi^-}\sqrt{s},$$

where $\sqrt{s}$ represents the energy of the mother particle $\Upsilon(3S)$, while E_{cms} is the energy in the center of mass of the di-pion system.
In absence of any enhancement, the SM process $\Upsilon(1S) \to \nu\bar{\nu}$ could be observed, improving the limits imposed by previous experiments.

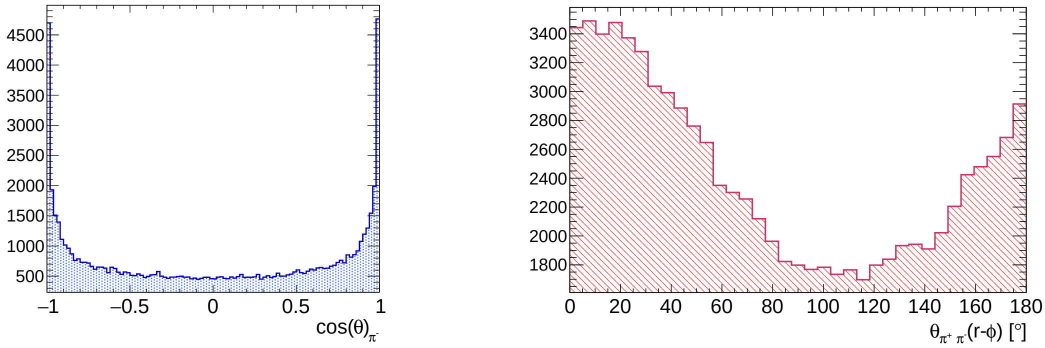
4.2 Control sample: $\Upsilon(1S) \to \mu^+\mu^-$

MonteCarlo simulations have been widely employed as a control sample to proceed with the current analysis; 10^5 collision events of

$$\begin{aligned} e^+e^- &\to \gamma_{ISR}\Upsilon(3S), \\ \Upsilon(3S) &\to \pi^+\pi^-\Upsilon(1S), \\ \Upsilon(1S) &\to \mu^+\mu^- \end{aligned} \tag{2}$$

have been generated within the BASF2 framework.
The importance and interest in the study of the visible channel lies in its double use. First of all, the physics which is behind it is already known and well tested as well; hence it can be used to ensure that the software has been correctly configured and that all the output distributions are in agreement with expectations, determined by the underlying physics rules for the specific process.
Among plenty of produced distributions, the most significative ones are here illustrated and in addition just for one of the two pions, since they share the same kinematics.
The angular distribution of the cosine of the pion polar angle $\cos\theta_\pi$ is shown in fig. 4.2(a). It is observed that most of the pions are emitted in the forward and backward directions, as expected from kinematics boundaries of the decay. Similar observations are obtained from the study of the distribution of the opening angle of the di-pion system $\theta_{\pi\pi}$ (fig. 4.2(b)).
Furthermore, the pion total momentum distribution is presented in fig. 7(a), showing that the maximum amount of pions is well concentrated around the mean value of half the total energy of the di-pion system, approximately 900 MeV. The correlation between the pions 4-momentum components has been investigated; in fig. 7(b) the correlation between the x components is shown. A preliminary analysis highlights background events due to mis-reconstructions. In order to reduce their total amount, a cut has been applied to all the momentum components, hence selected in a range between $(-1, 1)$ GeV/c.
Same quantities have been observed in case of $\Upsilon(1S)$ invisible decays, then confirming the goodness and reliability of the resulting simulation.
The last quantities that have been investigated in the visible decay are the invariant mass distributions for both $\Upsilon(1S)$ and $\Upsilon(3S)$ (fig. 8), showing perfect agreement in the peaking value with the PDG provided value [23]:

- $M_{\Upsilon(1S)} = 9650.30 \pm 0.26$ MeV/c^2
- $M_{\Upsilon(3S)} = 10355.2 \pm 0.5$ MeV/c^2



(a) *Distribution for the cosine of the polar angle for one of the two produced pions.*

(b) *Distribution for the opening angle of the di-pion system.*

Figure 6: Most significative angular distributions for the di-pion system.

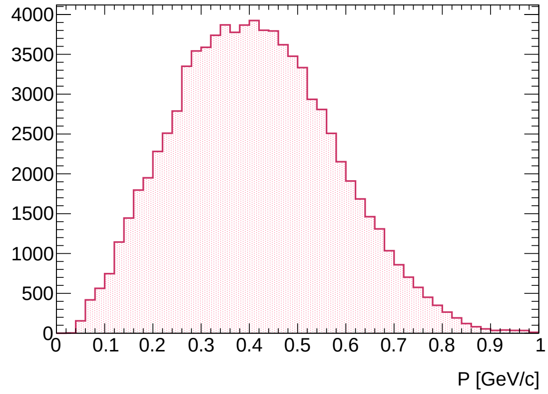
4.3 Signal and Background

Aim of the present work is to look at $\Upsilon(1S)$ invisible decays in the Belle II detector, via γ_{ISR} procedure, as shown in fig. 9.

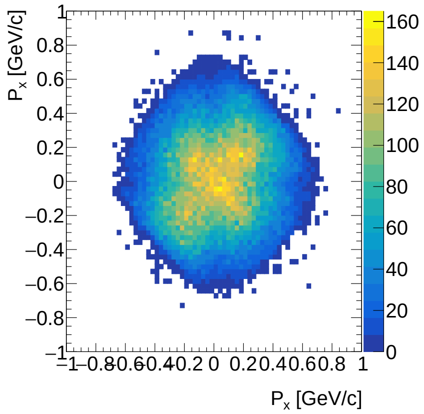
A typical signal event would look exactly as two charged particles, whose tracks are curving in the 1.5 T magnetic field, which are leaving energy deposits in all the various sub-detectors they are crossing. Those particles are the two pions, emitted directly by $\Upsilon(3S)$ decay, and represent the best resource to tag the subsequent $\Upsilon(1S)$ invisible decay, by looking at the recoil kinematics. Furthermore, it has been previously decided not to tag the initial state radiation low energy photon, which is usually emitted in the forward direction, mainly outside acceptance and, thus, lowering the reconstruction efficiency.

However, many other events can mimic the signal object of the analysis (eq. 4.1): not only QED combinatorial background, but also and especially the peaking background represent the main limitation for seeing any underlying signal around $\Upsilon(1S)$ mass resonance value. In deed, this effect is due to $\Upsilon(1S)$ decay into a couple of charged leptons (i.e. e^+e^-, $\mu^+\mu^-$ or $\tau^+\tau^-$), which are emitted in the forward and backward direction but outside the detector acceptance.

While the use of neural networks could in principle reduce the former, the latter requires only a very good estimation of the number of expected background events and its associated error, since it is irreducible due to the absence of a proper discriminating tool.



(a) *Pion total momentum distribution. The maximum available energy is given by the difference in mass between the mother particle* $\Upsilon(3S)$ *and the daughter* $\Upsilon(1S)$.

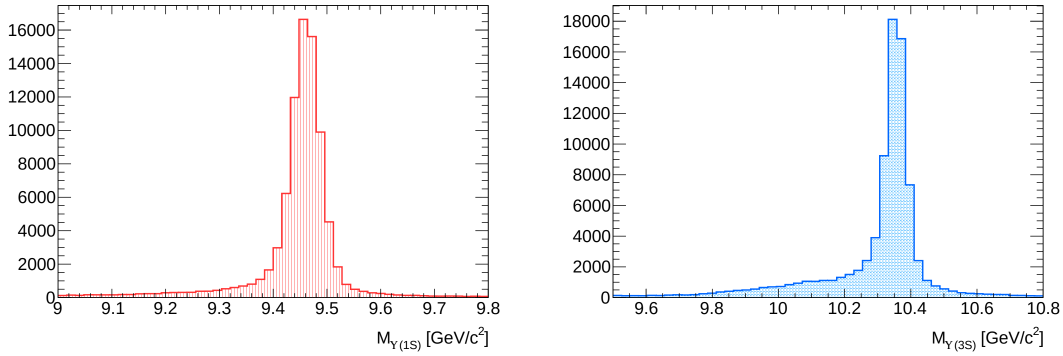


(b) *Correlation distribution for the two pions* P_x *component. Cuts selections in the range (-1,1) have been applied, in order to get rid of background mis-reconstructed events.*

Figure 7: Pions momentum distributions for the reconstructed visible decay in 4.2.

4.4 Total efficiency estimation for $\Upsilon(1S) \to \chi\bar{\chi}$

Before obtaining the final estimation of Belle II total efficiency for the decay channel in 4.1, the trigger technique of the Belle II experiment has been tested.
The main interest is to understand whether the standard trigger procedure could be adopted in the present analysis, namely the requiremenr for two *long tracks*, here converted in the two pions tracks going outside the CDC, and also to check if this technique is leading to a good total efficiency estimated value.
Effectively, those two pions are two low-momentum particles, generally turning inside the drift chamber and expiring there, sharing a maximum energy of 900 MeV since it corresponds to the difference in mass between the mother particle $\Upsilon(3S)$ and the daughter particle $\Upsilon(1S)$.
Finally, 10^5 collision events with studied decays have been generated inside Belle II detector and then reconstructed, in order to test the γ_{ISR} technique feasibility; however, it will require more investigation from the software point of view, since a more realistic model has to be implemented at the generation level for the initial state radiation photon.
By looking at the invariant mass of the system of pions (fig. 10(a)), it is observed that it is in agreement with the expected distribution [21]. Unfortunately no further information can be extracted from its study.
On the other side, the mass of the recoiling system against the given di-pion system reproduces exactly $\Upsilon(1S)$ invariant mass distribution, peaking at the expected value



(a) *Resulting distribution for the invariant mass of the reconstructed* $\Upsilon(1S)$. (b) *Resulting distribution for the invariant mass of the reconstructed* $\Upsilon(3S)$.

Figure 8: Invariant mass distribution for the particles $\Upsilon(1S)$ and $\Upsilon(3S)$, reconstructed in the visible decay in 4.2.

(fig. 10(b)), then showing that the invisible decay is correctly being reconstructed. Some effects on its slightly wider than expected shape could be due not only to the choice to discard the γ_{ISR} tag, but also to the approximations in the software development for this new technique and the used particle generation models.
According to previous trigger considerations, a preliminary estimation of the total efficiency can be obtained with the following requirements:

1. *Std trigger on two long tracks*: pions charged tracks seen outside the CDC;
2. *Cuts on pions 4-momentum components*: selection in the range between $[-1, 1]$ GeV/c, in order to better the ratio signal/background;
3. PID.

The resulting effect on the total momentum distribution for one of the pions is shown in figure 10(d).
In order to select only those detector regions where this low-momentum pions analysis cannot represent a significant background source, three different ranges have been selected in the pions opening angle distribution in the $r - \phi$ plane (fig. 10(c)), then determining the efficiency as:

$$\epsilon = \frac{N_{reconstructed}\ in\ \theta_{\pi\pi}}{N_{simulated}},$$

taking into account all previous requirements on cuts and PID.
The results for the Belle II total efficiency in the $\Upsilon(1S)$ invisible channel via γ_{ISR} procedure are shown in table 1.

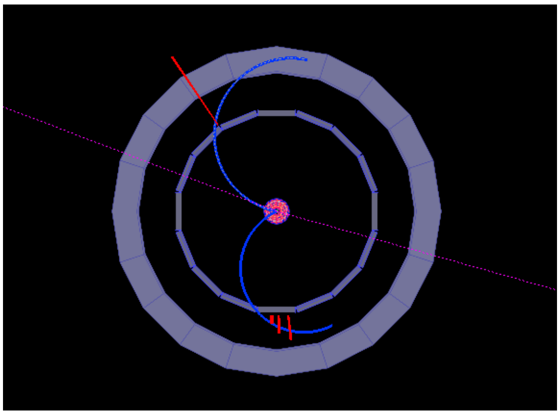


Figure 9: Illustration of an invisible decay simulated inside the Belle II detector (frontal view): the two blue curving lines represent two charged tracks belonging to the pions; the two purple-dashed lines symbolise the invisible decay products.

With the provided numbers, an estimate on the expected peaking background can be made. In case of the worst case scenario, far from the truth by order of magnitudes, it can be assumed that all the time that $\Upsilon(1S)$ is not reconstructed it is due to muons outside acceptance. Combining this study together with all the other $\Upsilon(nS)$ invisible decays, it will be possible to constrain this decay, setting an upper limit which is at the level of $\sim 4.3 \times 10^{-5}$, roughly 4.3 times larger than SM prediction and 8 times smaller than current upper limits from BABAR [22] (3×10^{-4}). It is assumed there will be at least an improvement of one order of magnitude over previous measurements.
However, looking at a more realistic situation and assuming that all the produced $\Upsilon(1S)$, the 0.026% will have the signature of $\Upsilon(1S)$ to invisible, due to decay products outside acceptance, then one can make an estimate of the number of peaking background events and of the associated error. By setting a constraint on the signal at 90% CL, Belle II will be able to observe this process if any efficiency of $\sim 13\%$ is achieved, which is above the obtained result. Further investigation will be needed to improve and correct the final estimation, however this preliminary result demonstrates that the di-pion transition and γ_{ISR} procedure is doable at the Belle II experiment. Any observed excess in the recoil mass distribution could be interpreted as a signal of new physics.

5 Conclusions

In 2017 the high precision Belle II experiment will start collecting data at various center of mass energies, aiming to reach an integrated luminosity of 50 ab^{-1}. In

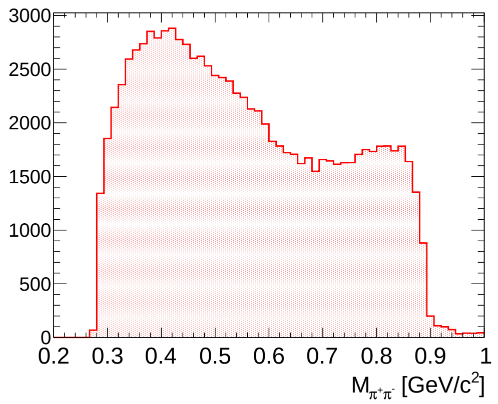
Table 1: Obtained results for the total efficiency estimation in the γ_{ISR} procedure, together with the determined detector acceptance. Different values are shown, according to the selected range in the opening angle $\theta_{\pi\pi}$ distribution.

Detector acceptance	$\sim 87\%$
Total efficiency (Trigger+PID+Cuts)	
$\pi - \pi$ opening angle	N events
$[0° - 180°]$	$\sim 47\%$
$[100° - 180°]$	$\sim 19\%$
$[130° - 180°]$	$\sim 14\%$

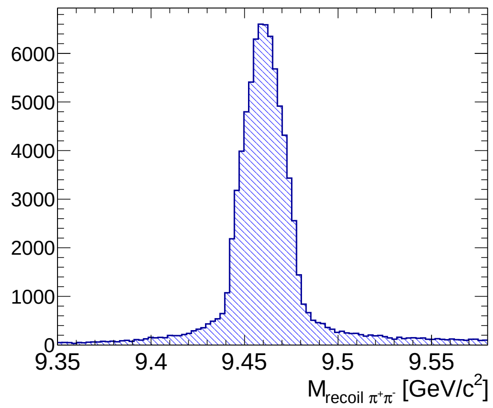
this scenario low-mass dark matter searches could be realized, thus motivating feasibility studies of decays where DM might show up at Belle II, e.g. the invisible decay:

$$e^+e^- \to \gamma_{ISR}\Upsilon(3S),$$
$$\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S),$$
$$\Upsilon(1S) \to \chi\bar{\chi}$$

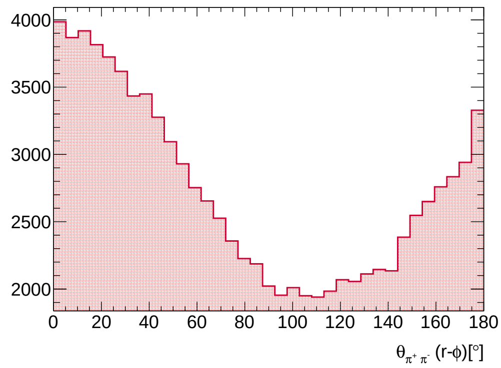
technique which has never been studied before; furthermore Belle II trigger system has been optimized for other kind of measurements. For this reason, in this work standard trigger requirements (requirement for two long tracks outside the CDC) have been adopted and tested, in order to get a final estimation of the detector acceptance, the reconstruction and the total trigger efficiencies and hence of the feasibility of the γ_{ISR} procedure. Control samples of $\Upsilon(1S)$ visible decays have been used as a further check on the goodness and reliability of the simulated sample. The total efficiency for the studied invisible decay is $\sim 14\%$, in a range of opening angle between pions between $[130° - 180°]$.
According to obtained results, Belle II will be able to search for DM, using the γ_{ISR} technique.



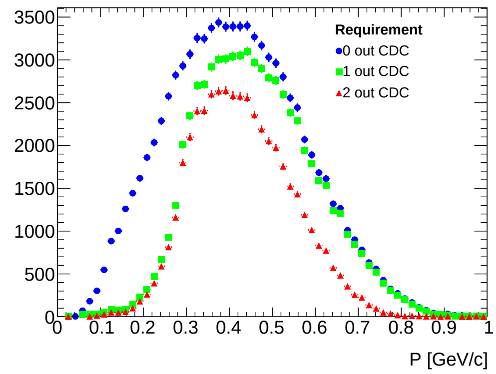
(a) *Distribution of the invariant mass of the di-pion system.*



(b) *Recoil mass distribution against the di-pion system: it represents $\Upsilon(1S)$ invariant mass distribution.*



(c) *Opening angle $\theta_{\pi\pi}$ distribution.*



(d) *Pion total momentum distribution, according to different trigger selections. The blue curve corresponds to the basic requirement of both charged tracks seen in the CDC, the green one is related to the quest for one long, while the red one for two long tracks out of the CDC.*

Figure 10: Final distributions for the di-pions system in $\Upsilon(1S)$ invisible decay, via γ_{ISR} procedure.

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