NEW PHYSICS OPPORTUNITIES IN THE CHARM/TAU REGION: THE BESIII — EXPERIMENT IN BEIJING*

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A new facility for precision physics in the charm/tau energy regime has become operational at the Institute for High Energy Physics (IHEP) in Beijing, China. It features the dual ring e^+e^- collider BEPCII operating at luminosities up to $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and at a centre-of-mass energy between 2 GeV and 4.6 GeV. BESIII, a new state-of-the-art detector has been built and successfully commissioned. This contribution describes the facility, presents a brief overview of the physics program and shows preliminary results from first run in spring 2009 which collected a sample of 156 pb^{-1} at the $\psi(2S)$ resonance.

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1. Introduction

Electron–positron colliders have been at the forefront of research in hadron and particle physics since many years. Their rich physics potential arises from the fact that e^+e^- annihilation produces a virtual photon with

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well defined $J^{PC} = 1^{--}$ quantum number which couples to charged leptons and quarks. Depending on the CM energy of the collider, different regions of interest can be accessed. The Phi factory at Frascati, the BEPCII collider at IHEP Beijing and the KEKb collider at Tsukuba are examples of contemporary colliders focussing on ϕ meson and kaon production, charm/tau physics and B physics, respectively. Due to the versatility of such machines, there is a very long history of e^+e^- colliders.

The new BEPCII e^+e^- collider at IHEP Beijing became recently operational, operating already at record luminosities. A new state-of-the-art experiment, the BESIII detector has been built, successfully commissioned and is ready to address a wide range of physics topics in hadron physics and particle physics.

2. The BEPCII e^+e^- collider

BEPCII is a double-ring e^+e^- collider designed for a peak luminosity of $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at a beam current of 0.93 A. The luminosity of BEPCII is a factor of 100 larger compared to its predecessor, the BEPC collider. BEPCII consists of two storage rings with 237.5 m circumference. Each of the two rings stores 93 bunches with a bunch length of 1.5 cm. At the interaction point the beams are colliding with a horizontal crossing angle of 11 mrad and a bunch spacing of 8 ns.

The energy per beam ranges between 1.0 GeV and 2.3 GeV, with the optimum beam energy at 1.89 GeV. The energy spread amounts to 5×10^{-4} GeV. In summer 2008, the BEPC2 accelerator and the BESIII experiment at IHEP Beijing were successfully commissioned. A first run took place in November 2008 collecting about 14 Million $\psi(2S)$ events. In March and April 2009, a sample of 156 pb^{-1} corresponding to 106 M $\psi(2S)$ events was collected with BEPCII operating at about 30% of the peak luminosity.

3. The BESIII detector

The BESIII detector [1] features a large geometrical acceptance of 93% of 4π. Charged particle tracking is performed with a 43-layer mini drift chamber (MDC) system with 6796 signal and 21884 field wires. The gas mixture of He (40%) and C_3H_8 (60%) has been optimized for best position resolution and large radiation length. The average single wire resolution is 135 μm. The chambers operate in a solenoidal magnetic field of 1 Tesla which is produced by a superconducting magnet. The momentum resolution for charged particles amounts to 0.5% at 1 GeV/c.

The high performance electromagnetic calorimeter (EMC) is divided into a barrel section and two endcap sections with a total of 6240 CsI(Tl) crystals. At 1.0 GeV, the energy resolution is 2.5% and 5% in the barrel and the endcaps, respectively. A position resolution of 6 mm and 9 mm for the barrel and the endcaps, respectively, is achieved.

A time-of-flight system (TOF) constructed of 5 cm thick plastic scintillation detectors serves for particle identification. The barrel portion employs 176 detectors with a length of 2.4 m arranged in two layers. The endcaps are covered by 96 fan-shaped scintillators. The time resolution amounts to 80 ps for the barrel and 110 ps for the endcaps, respectively. This provides a 2σ K/π separation up to about 1.0 GeV/c.

The muon system (MUC) consists of 1000 m^2 of Resistive Plate Chambers (RPCs) with a position resolution of about 2 cm, comprising nine barrel and eight endcap layers.

BESIII is a state-of-the-art detector which is in many respects similar to the CLEOc detector. A schematc view of the detector with its main components is shown in Fig. 1. Fig. 2 shows the first event which was recorded with BESIII on July 19, 2008.

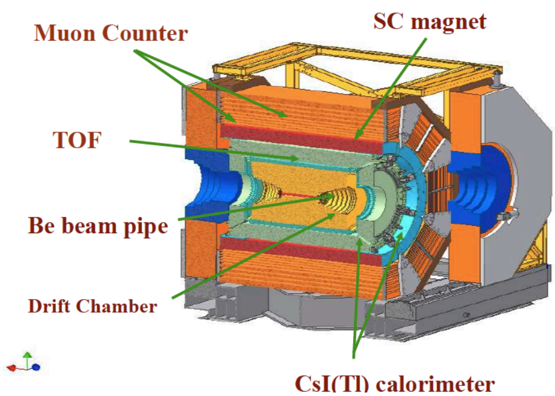

Fig. 1. The BES3 detector [1], featuring tracking with Mini Drift Chambers (MDC), an electromagnetic calorimeter (EMC) consisting of 6240 CsI(Tl), a time-of-flight system for particle identification and an RPC based muon detection system.

4. Physics program

BES3 features a comprehensive physics program which benefits from the unprecedented luminosity of BEPCII and the high performance BESIII detector which is able to measure charged particles as well as photons over the relevant momentum range with excellent resolution and particle identification capabilities.

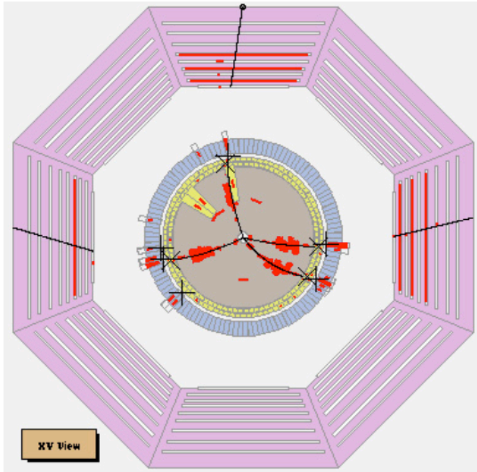

Fig. 2. The first event recorded with BESIII on July 19, 2008.

The energy regime of BESIII is of particular interest in that it allows the precision investigation of numerous narrow resonances in the charmonium region. Going beyond improved measurements of known branching fractions, near threshold the possibility of tagging permits almost background-free studies of rare channels. Moreover, many of the recently discovered X,Y,Z — states are accessible at BESIII and could be studied with improved precision.

Measurements of the total cross-section for e^+e^- annihilation into hadrons are indispensable input for the determination of the nonperturbative hadronic contribution to the running QED fine structure constant and an essential input parameter in precision electroweak measurements.

Furthermore, the charm region presents a challenge for lattice QCD (LQCD) calculations. Measured properties such as D meson decay constants or transition form factors can be compared to results of LQCD, thereby probing the precision of such calculations. Such studies are crucial to cut down errors on hadronic observables for precision CKM physics.

Since charmonium decays are a rich source of gluons, there is a significant discovery potential for QCD exotica such as glue balls, multi-quark states and hybrids. Furthermore, meson and baryon spectroscopy will benefit from the high luminosity and high quality detection, including neutral channels.

Improved precision for the τ lepton mass can be achieved by threshold scans employing a precision laser backscattering system for energy measurement.

A comprehensive description of the physics program can be found in the BESIII physics book [2].

5. First results

The data which will be presented in the following have been collected in a run where 106 M $\psi(2S)$ events have been recorded. It should be noted that all results given below are preliminary.

5.1. χ_c states

Fig. 3 shows part of the charmonium level scheme below the open charm threshold. The arrows mark radiative decays between the $\psi(2S)$ state and various χ_c states as well as radiative decays of χ_c states to J/ψ. Fig. 4 shows the inclusive gamma ray spectrum observed at the $\psi(2S)$ resonance. E1-transitions corresponding to the decays $\psi(2S) \to \chi_{c2}(^13P_2)$, $\chi_{c1}(^13P_1)$, $\chi_{c0}(^13P_0)$ are observed. Furthermore, the decays $\chi_{c2}(^13P_2)$, $\chi_{c1}(^13P_1) \to \gamma J\psi$ are seen.

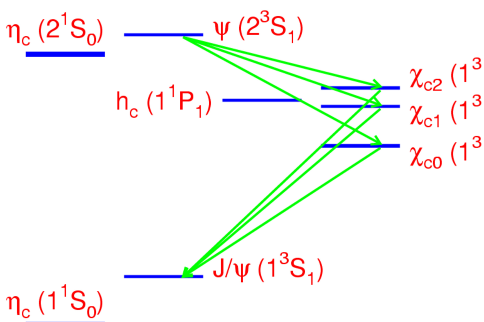

Fig. 3. Charmonium levels scheme below the open charm threshold. The arrows mark radiative decays between the $\psi(2S)$ state and various χ_c states as well as radiative decays of χ_c states to J/ψ.

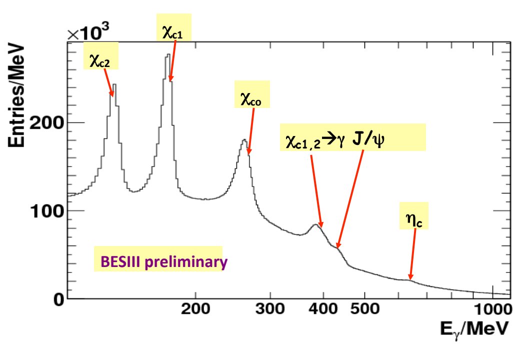

Fig. 4. Inclusive γ ray spectrum. The decays $\psi(2S) \to \chi_{c2}(^13P_2)$, $\chi_{c1}(^13P_1)$, $\chi_{c0}(^13P_0)$ as well as $\chi_{c2}(^13P_2)$, $\chi_{c1}(^13P_1) \to \gamma J\psi$ are seen.

5.2. Observation of the h_c

The spectrum of charmonium states can be quite well described with potential models assuming a one gluon exchange Coulomb-like term and a linear confining term. In more refined models, spin-dependent terms have to be considered. Information about the spin-dependent interaction can be obtained from a precision measurement of the $1P$ hyperfine mass splitting. Despite of many extensive studies of the charmonium system, the properties of the $c\bar{c}$ singulet state $h_c(^11P_1)$ state are not well known. CLEOc has measured the mass of the h_c [3] both in the exclusive process $\psi(2S) \to \pi^0 h_c \to \pi^0\gamma\eta_c$ as well as in the inclusive process $\psi' \to \pi^0 h_c$ where the h_c shows up as a peak in the π^0 recoil mass distribution. E835 has observed [4] the decay $h_c \to \gamma\eta_c$.

With BES3, we have studied h_c production and decay at the $\psi(2S)$ resonance, both in the recoil mass distribution of inclusive π^0 production and in γ-tagged events from the process $\psi' \to \pi^0 h_c \to \pi^0\gamma\eta_c$. Fig. 5 shows the π^0 recoil mass distribution of $E1-\gamma$-tagged events of the type $\psi(2S) \to \pi^0 h_c \to \pi^0\gamma\eta_c$. A clear h_c signal is observed with the mass of $(3525.16 \pm 0.16 \pm 0.10)$ MeV and the width of $(0.89 \pm 0.57 \pm 0.23)$ MeV can be extracted. The latter has been measured for the first time.

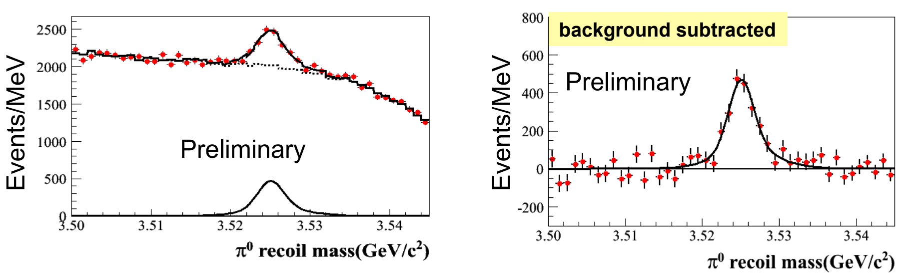

Fig. 5. π^0 recoil mass distribution of E1–γ-tagged events of the type $\psi(2S) \to \pi^0 h_c \to \pi^0\gamma\eta_c$(left) and with subtracted background (right). A clear h_c signal is observed.

Combining the inclusive measurement shown in Fig. 6 with the γ-tagged measurement, the absolute branching ratios of $\psi' \to \pi^0 h_c$ and $h_c \to \gamma\eta_c$ have been determined for the first time as $(8.42 \pm 1.29(\text{stat})) \times 10^{-4}$ and $(55.7 \pm 6.3(\text{stat}))\%$. As noted above, these results are preliminary and systematic errors are currently under study.

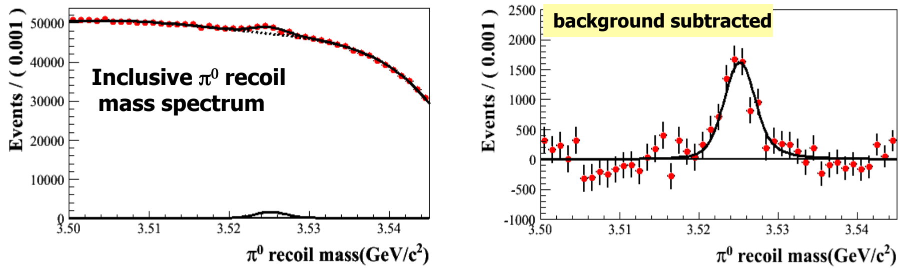

Fig. 6. π^0 recoil mass distribution of inclusive events of the type $\psi(2S) \to \pi^0 X$(left) and with subtracted background (right). A clear h_c signal is observed, albeit with larger background when compared to the E1–γ-tagged data (see Fig. 5).

5.3. χ_c decays into $\pi^0\pi^0$ and $\eta\eta$ final states

Since the electromagnetic interaction conserves C-parity, χ_c states cannot be directly formed in e^+e^- annihilation. However, they can easily be studied as products of radiative $\psi(2S)$ decays (see Fig. 4) in a nearly background-free environment. Among the various hadronic decay channels of χ_c mesons, channels with two neutral pseudoscalar mesons are the most accessible, both from the experimental point of view [5] as well as in model descriptions [6].

Fig. 7 shows shows the radiative photon spectrum for events with two reconstructed π^0 mesons (left) and two reconstructed η mesons (right). The two observed peaks correspond to the processes $\psi(2S) \to \gamma\chi_{c2}$ and $\psi(2S) \to \gamma\chi_{c0}$.

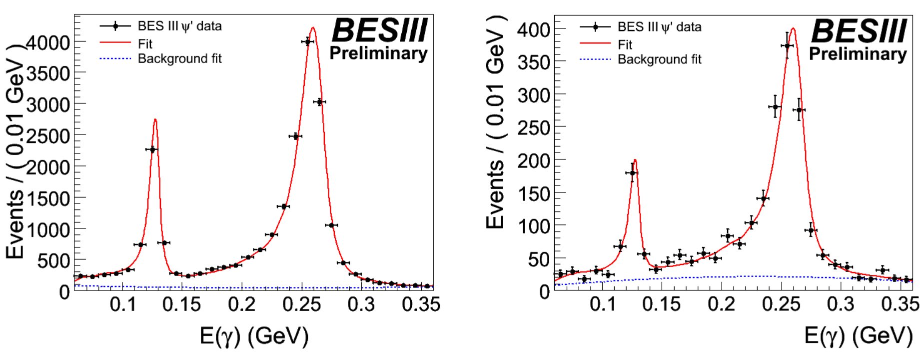

Fig. 7. Radiative photon spectrum for events with two reconstructed π^0 mesons (left) and two reconstructed η mesons (right). The two observed peaks correspond to radiative decays of $\psi(2S)$ into χ_{c2} (left peak) and χ_{c0}(right peak). The background has been studied with Monte Carlo simulations including potential background channels listed in the PDG [7].

The extracted branching fractions are shown in Table I and compared to previous results from CLEOc [5] and PDG values [7]. Again, systematic errors are under study.

TABLE I

Extracted branching fractions (preliminary) and comparison to previous results from CLEOc [5] and PDG values [7]. Systematic errors are currently under study.

BR(10^3)		χ_{c0}	χ_{c2}
$\pi^0\pi^0$	BESIII	3.25 ± 0.03(stat)	0.86 ± 0.02(stat)
	PDG	2.43 ± 0.20	0.71 ± 0.08
	CLEO-c	$2.94 \pm 0.07 \pm 0.35$	$0.68 \pm 0.03 \pm 0.08$
$\eta\eta$	BESIII	3.1 ± 0.1(stat)	0.59 ± 0.05(stat)
	PDG	2.4 ± 0.4	< 0.05
	CLEO-c	$3.18 \pm 0.13 \pm 0.35$	$0.51 \pm 0.05 \pm 0.06$

6. Conclusions

With the BEPC2 collider and the BESIII experiment, a new state-of-the art facility for physics in the charm/tau region has become operational. Record luminosities will provide high quality data improving the experimental knowledge in a multitude of fields such as light hadron spectroscopy, charmonium spectroscopy, open charm physics and the search for rare and forbidden decays.

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