Chapter 10

OUTLOOK

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1 THE RENAISSANCE OF HEAVY QUARKONIUM PHYSICS

Quarkonium physics has played a fundamental role in the development of quantum chromodynamics. It may play an even more relevant role now for QCD, the Standard Model, and physics beyond the Standard Model. Heavy quarkonium, being a multiscale system, offers a precious window into the transition region between high-energy and low-energy QCD and thus a way to study the behaviour of the perturbative series and the nontrivial vacuum structure. The existence of energy levels below, close to and above threshold, as well as the several production mechanisms, allows one to test the population of the QCD Fock space in different regimes and eventually to search for novel states with nontrivial glue content (hybrids, glueballs). Precise determinations of Standard Model parameters from quarkonium systems have become possible because of the level of precision reached by the experimental data and by the most recent developments in effective field theories and lattice QCD. Moreover, the clean signature of heavy quarkonium in heavy-ion collisions provides a perfect probe of in-media phenomena, and eventually of quark–gluon plasma formation and the confinement–deconfinement transition in QCD. The expected large statistics of ψ and Υ resonances to be collected in the next few years at e^+e^- and hadronic colliders makes heavy quarkonium physics also suitable for searches for new particles and new phenomena. A number of new physics scenarios can be constrained or discovered in the near future, ranging from the contribution of supersymmetric particles or extended Higgs sectors in quarkonium decay, to lepton flavour violation tests, CP tests and chromo-dipole moments of quarks. All these studies will play a major role in the test of extensions of the Standard Model, and will be complementary to direct searches at colliders like the LHC or a future linear collider.

2 OPPORTUNITIES IN THEORY AND EXPERIMENT

The future relevance of quarkonium physics will be proportional to the number of observables that can be rigorously described in terms of the Standard Model and its parameters and well measured by experiments. The enormous progress made in this direction in recent years is the reason for the quarkonium renaissance that we are witnessing today and that has been documented in this report. It comes mainly from QCD effective field theories in either their continuum or in their lattice versions, while phenomenological models have played (and will still play in the future) a crucial role in suggesting experimental search strategies and interpreting new results. In order to achieve further progress it will be important to complete the following general programme.

(1) Adopt a common, model-independent, EFT-based, language to describe all aspects of heavy quarkonium physics. This has not been achieved yet for all observables, and, noteworthily, not for observables sensitive to threshold effects, where phenomenological models still provide the only available theoretical tool.

(2) Improve the determination of the nonperturbative parameters that describe the low-energy dynamics either by experimental data or by lattice calculations. In an EFT context the number of these parameters is finite. Therefore, precise quarkonium data are important today more than ever.

They may check factorization, allow for precise extractions of the Standard Model parameters, and severely constrain theoretical determinations and predictions.

We note that the more progress there is in (1), the more importance that experimental data will acquire for (2).

In the following we discuss progress expected or invoked for some specific set of observables.

2.1 Quarkonium ground and lower states

Ground-state observables and to a lesser extent low lying quarkonium-state observables may be studied in the framework of perturbative QCD. These studies are relevant because they may allow, in principle, the precise extraction of some of the fundamental parameters of the Standard Model, such as the heavy quark masses and the strong coupling constant (see Chapter 6). B_c will be copiously produced at future hadron colliders and will allow the determination of the electroweak parameters of the Standard Model, such as the CKM matrix elements and CP violating parameters (see Chapter 4). However, the accuracy with which the fundamental parameters can be measured is at present limited by nonperturbative contributions whose form is in many cases known, but whose size is not known with sufficient precision. Therefore the main theoretical challenge is the precise determination of these nonperturbative contributions (see Chapters 3 and 4). On the other hand we could take the opposite approach and use the lower quarkonium states as a theoretically clean environment to study the interplay of perturbative and nonperturbative effects in QCD and extract nonperturbative contributions by comparison with data. A few examples are:

- The η_b has been intensively searched for at the Tevatron and CLEO. Theoretically several observables related to the production mechanism (Chapter 5), spectroscopy (Chapter 3), and decay (Chapter 4) have been studied. Most likely, the η_b discovery will come from the Tevatron experiments CDF and D0. NRQCD predictions suggest ($\sigma_{\eta_b+X} \approx 2.5\ \mu$b at 1.96 TeV), so that η_b should be found during Run II. However, as the decay rates are expected to be very low, reliable theory estimates for the decays into $J/\psi J/\psi$, $D\bar{D}\pi$, $K\bar{K}\pi$ are important. Indications can also come from the efforts made to detect its charmonium analogue, the η_c, in hadronic collisions. An eventual discovery will put severe constraints on the size of the nonperturbative corrections and confirm or disprove our current understanding of the bottomonium ground state. In case this system, as expected, turns out to be mainly perturbative, it will provide, combined with the $\Upsilon(1S)$, a very precise measurement of $\alpha_{\rm s}$.
- The perturbative $\Upsilon(1S)$ mass is used for a competitive determination of m_b. However, at present accuracy, perturbation theory has difficulty reproducing the measured width $\Upsilon(1S) \to e^+e^-$. Given the importance of this quantity, the origin of these difficulties should be clarified. Furthermore, the experimental determination of the $\Upsilon(1S)$ polarization at the Tevatron is roughly consistent with the NRQCD prediction, and fixed-target experiments find an almost transverse polarization for the $\Upsilon(2S)$ and $\Upsilon(3S)$ (although the experimental result disagrees with NRQCD for the $\Upsilon(1S)$). This provides a strong motivation for measuring the polarization of all three resonances at the Tevatron. However, because of the large bottom mass, the fragmentation mechanism does not dominate until relatively high values of $p_{\rm T}$ are reached ($p_{\rm T} > 10$ GeV). LHC experiments will likely play a decisive role in settling this issue because of the broader $p_{\rm T}$ range.
- The B_c mass determined by experiments is affected at present by about 400 MeV uncertainty, while theoretical calculations based on perturbative QCD are affected by errors which are not larger than 30 MeV (see Chapter 3). Again a precise determination of the B_c mass will strongly constrain the size of the nonperturbative contributions and confirm or disprove our understanding of this system in terms of perturbative QCD. An analogous argument holds for the yet undiscovered B_c^*.
- Baryons with two or three heavy quarks and in particular the yet undiscovered baryons with two bottom quarks will offer a completely new system to test our understanding of low-lying heavy

quarkonium resonances (see Chapter 3). The study of these systems from QCD is just beginning with lattice simulations just starting to analyse these systems. Further progress is expected in the future, in particular if driven by new experimental findings.

- As the $\eta_c(2S)$ and h_c complete the low-mass charmonium multiplets, the theoretical understanding of fine and hyperfine splittings is far from the precision reached by experiments (see Chapter 3). Further progress in unquenched lattice calculations is needed. The plans to produce very large ($> 10^9$) samples of J/ψ's and $\psi(2S)$'s can open the era of 1–2% precision measurements on many radiative transitions, allowing access to the suppressed (M1, M2 and E2) amplitudes, which are mostly dependent on higher-order corrections and better test different theoretical approaches. Runs at the $\psi(2S)$ energy will also provide a very large sample of tagged J/ψ decays (as more than half of these mesons decay to J/ψ), but are also an excellent source of χ_c's, and, as recently shown, of h_c's.
- At last, B factories will allow us to reach accuracies better than 10% on the $\gamma\gamma$ widths of the $\eta_c(1, 2S)$ and $\chi_{c0,2}$, by the proper combination of their data with measurements from $\mathrm{p\bar{p}}$ and τ-charm factories. Electromagnetic and hadronic decay widths, whose experimental accuracy is already sensitive to NLO corrections (see Chapter 4), may in perspective provide a competitive measurement of α_s at charmonium energies.
- In the LHC era, very large samples ($>10^{10}$ events) of J/ψ and $\psi(2S)$ mesons will allow the high-precision test of lepton flavour violation, severely constraining new physics models. Lepton flavour violation can be tested via two-body decay, $J/\psi \to \ell\ell'$ (which conserves total lepton number), with ℓ and ℓ' denoting charged leptons of different species. This process (discussed in Chapter 8) could occur at tree-level induced by leptoquarks, sleptons (both in the t channel) or mediated by Z' bosons (in the s channel).

2.2 Higher quarkonium states

The rigorous study of higher quarkonium states, including exotic states like hybrids, will mostly rely on lattice calculations. However, at the moment, phenomenological models still play a major role in describing states above the open flavour threshold. In the framework of nonrelativistic EFTs on the lattice, further progress will need:

- the calculation in lattice perturbation theory of the Wilson coefficient of the EFT at least at NLO (see Chapters 1 and 3);
- the lattice implementation of lower-energy EFTs like pNRQCD. In this framework the lattice data would provide the form of the potentials and the states would be determined by solving the corresponding Schrödinger-like equation.

The observation of the $X(3872)$ is the start of challenging searches for non-vector states across the open flavour threshold. This is probably the richest experimental field of research on heavy quarkonia at present. As mentioned above, phenomenological models have played a particularly important role in predicting which states are likely to be narrow enough to be observed and suggesting the most promising channels for their observation.

- Studies on the nature of the $X(3872)$, described in Chapters 3, 4, and 5 can benefit from data taking at B factories, Tevatron, and even τ-charm factories: these should have high priority, as emphasized throughout the report.
- Given the excellent momentum resolution of the B factories and the unexpected double charm process, J/ψ recoil techniques also have good discovery potential. More conventional methods, like the study of the production of pairs of open charm mesons near threshold (in B decays and hadronic collisions) are now reaching the statistics necessary to allow the discovery of new resonances in the $c\bar{c}$ system with quantum numbers other than 1^{--}. In particular, the remaining

$1D$ states, some of the $2P$ states and the 3^1S_0 are likely to be observable in this way. Observation of new states with different quantum numbers is also beneficial for the understanding of the mechanism of charmonium production.

- The current CLEO-c run at $\psi(3770)$ energy, presently measuring f_D from $\bar{D}D$ decays, can also look for rare radiative and hadronic decays to lower $c\bar{c}$ states. This study can give a unique insight into the S–D mixing and coupling to decay channel effects. It may also give clues to the understanding of the ρ–π puzzle.

2.3 Production

If measurements of quarkonium production are to be exploited fully to test theoretical models, then the precision of the theoretical predictions should be improved. Several theoretical tools that are, by now, standard could be applied to increase the precision of theoretical predictions for charmonium and bottomonium production rates. These tools include calculations at NLO in α_s and v, resummation of logarithms of m^2/p_T^2 or $m^2/(p^*)^2$, resummation of logarithms of p_T^2/m^2 or $(p*)^2/m^2$, resummation of logarithms of s/m^2, resummation of logarithms of $1 - z$, and lattice calculations of quarkonium matrix elements.

- Calculations of cross-sections at NLO in α_s already exist for total cross-sections and for some quarkonium fragmentation functions. NLO calculations of quarkonium differential cross-sections in the colour-singlet model also exist. However, full NLO calculations in the NRQCD factorization approach are lacking, in general, for quarkonium differential cross-sections and, in particular, for the important cases of quarkonium cross-sections that are differential in p_T.
- Some calculations of corrections of higher order in the heavy-quark velocity v have already been carried out and have yielded large corrections. It is important to investigate such higher-order corrections for all quarkonium production processes and to develop a phenomenology of the higher-order NRQCD matrix elements. It is also important to understand the origins of large corrections of higher order in v, with the aim of controlling them to all orders in the v expansion.
- Logarithms of m^2/p_T^2 are important at small p_T. Their resummation involves the introduction of non-perturbative k_T-dependent parton distributions. The effects of these distributions are small for bottomonium, but are important for charmonium. It may be possible to work out a phenomenology of such distributions by exploiting their universality properties to extract them from processes other than quarkonium production, such as Drell–Yan production of lepton pairs.
- Logarithms of p_T^2/m^2 are important at large p_T. They may have a large effect on, for example, extractions of the $^3S_1$ colour-octet matrix elements that dominate J/ψ and Υ production at large p_T.
- Logarithms of s/m^2 may play an important rôle in diffractive quarkonium production and quarkonium production in which sub-processes involve small momentum transfer. They are often resummed in existing calculations in the k_T-factorization approach by making use of the BFKL equation. Large corrections that occur at NLO in the BFKL equation cast some doubt on the accuracy of such resummed calculations.
- The quantity $1 - z$ generally measures the departure of a quarkonium production process from a kinematic endpoint. Examples of z are the quarkonium energy fraction and the quarkonium longitudinal-momentum fraction. It follows that logarithms of $1 - z$ are important near the kinematic limits of cross-sections. Their resummation involves nonperturbative shape functions. It would be useful to develop a phenomenology of these shape functions so that information from, say, quarkonium production in e^+e^- collisions could be used to make predictions for other quarkonium production processes, such as photoproduction at HERA.
- Lattice techniques can be used to compute colour-singlet NRQCD production matrix elements in the vacuum-saturation approximation, and, hence, to supplement information on the values of

these matrix elements that can be obtained from the phenomenology of quarkonium decay and production. Unfortunately, it is not yet known, except within the vacuum-saturation approximation, how to formulate the problem of the calculation of production matrix elements in lattice field theory. In particular, no lattice method exists for the computation of colour-octet production matrix elements.

In addition to the logarithmic contributions that we have already mentioned, large non-logarithmic contributions appear in some calculations of production cross-sections at NLO in $\alpha_{\rm s}$. Examples of large corrections also exist in NLO calculations of quarkonium decay rates. It is important to understand the origins of such large corrections and to bring them under control to all orders in $\alpha_{\rm s}$.

A significant theoretical issue is the correctness of the NRQCD factorization formula for production. An all-orders perturbative proof of the factorization formula would be an important step forward. Such a proof might establish that there is a range of validity of the factorization formula. For example, the formula might hold at large $p_{\rm T}$, but not at small $p_{\rm T}$ or for total cross-sections. Most of the experimental data are at small $p_{\rm T}$. Experiments at small $p_{\rm T}$ are important to fix the values of certain NRQCD matrix elements and, hence, to test matrix-element universality. However, theoretical confidence in NRQCD factorization is highest at values of $p_{\rm T}$ that are significantly larger than the heavy-quark mass. Therefore, it is also important for experiments to obtain data points with the highest possible statistics at the largest accessible values of $p_{\rm T}$. Such high-$p_{\rm T}$ measurements are particularly important in testing the key prediction that, owing to the colour-octet mechanism, there should be a large transverse polarization in spin-triplet quarkonium produced at large $p_{\rm T}$.

The results from the Belle Collaboration on inclusive and exclusive double $c\bar{c}$ production in e^+e^- collisions are strongly at odds with current theoretical calculations. These calculations are carried out, essentially, within the colour-singlet model. However, colour-octet corrections are absent at leading twist in the exclusive case and are expected to be small in the inclusive case. An independent check of the Belle Collaboration results would be welcome. If these results are confirmed, they would pose a severe challenge to the current theoretical thinking about double $c\bar{c}$ production in e^+e^- collisions. A measurement of the double $c\bar{c}$ production cross-section in $\rm p\bar{p}$ collisions at the Tevatron might give some additional clues as to the nature of the production mechanisms.

Polarized beams are available at RHIC and may be available at the LHC. Polarized-beam measurements of quarkonium production rates might be useful in discriminating between various models for quarkonium production and between various production mechanisms within the NRQCD factorization approach. Exploratory theoretical work on quarkonium production cross-sections for polarized beams is needed in order to understand the potential of such measurements.

2.4 In media

The study of quarkonia in media is relevant because one may use the media as a filter to study the time and length scale associated with quarkonia production and thus learn more about the production mechanism. Moreover, one may use quarkonia as a test of the medium to find out its properties (e.g., whether it is hadronic or deconfined). It has been suggested that production and suppression of quarkonia in heavy-ion collisions could signal deconfinement and quark–gluon plasma formation and eventually estimate its temperature (see Chapter 7). To use quarkonium to study the quark–gluon plasma one needs to understand its properties inside the plasma using lattice QCD and understand its formation in a high density environment. A list of future challenges related to these issues may consist of the following.

- Several lattice QCD studies show that ground-state charmonia survive in the plasma at temperatures as high as $1.5\,T_{\rm c}$. At the same time all these studies show strong lattice artefacts in the charmonium spectral functions. Better lattice actions are needed to reduce these artefacts (e.g., lattice NRQCD, perfect actions).
- It would be important to understand what governs the quarkonium suppression in the plasma. In this respect it would be extremely interesting to study the bottomonium system and see whether or

not the $1P$ bottomonium states (χ_b), which are expected to have the same size as the J/ψ, melt at the same temperature.

- It is expected that the medium created in heavy-ion collisions is not fully equilibrated. Thus it would be very important to determine the thermal width of different quarkonium states on the lattice to make contact with experiments.
- In heavy-ion collisions at very high energy, the initial state is given by coherent gluon fields, the so-called colour glass condensate with typical momentum scale (saturation scale) $Q_s \simeq$ 1–2 GeV. In the presence of colour glass condensate, heavy-quark and quarkonium production may be quite different from superposition of proton–proton production at the same energy. A detailed proton–nucleus study is needed together with nucleus–nucleus experiments to study this issue.
- Hydrodynamic models suggest a fast equilibrization in heavy-ion collisions at RHIC which will be even faster at LHC. The time scale of quark–gluon plasma formation $\tau \simeq 0.6$ fm is comparable to the time scale of the quarkonium formation. In order to disentangle between possible effects in quarkonium yield due to in-medium production from true medium effects, e.g., screening, a detailed analysis of quarkonium yields versus rapidity, energy, and $p_{\rm T}$ is required.

2.5 Top–antitop production

Top–antitop quark-pair production will provide an integral part of the top-quark physics programme at the International Linear Collider (ILC), which after the decision for cold, superconducting technology, is now becoming an inter-regional endeavour. A precise measurement of the threshold cross-section can provide a top-quark mass determination with uncertainties at the level of 100 MeV, a measurement of the total top decay rate Γ_t, the coupling strength of top quarks to gluons, $\alpha_{\rm s}$, and, if the Higgs boson is light, the top Yukawa coupling. For more details see Chapter 6.

On the theoretical side there are a number of problems that need to be solved. Among them are the still missing NNLL corrections to the top-pair production current, which affect the theoretical uncertainties of the cross-section normalization. Also, a complete fixed-order prediction at NNNLO of the total cross-section would be desirable as a cross-check of the importance of the summation of logarithms and as a starting point to renormalization group improved calculations beyond the NNLL level. An important conceptual issue to be solved is a consistent treatment of the interplay of electroweak and QCD effects. Since the top quark decay is a leading order effect in the threshold region, this problem includes the consistent treatment of interference effects of top quark production and decay, of factorizable and non-factorizable corrections and also of non-resonant final states. Closely related is also the problem of rescattering corrections.

Top quark threshold dynamics may also play a role in other processes at high energy. For example, the process $\gamma\gamma{\to}t\bar{t}$, accessible through the option of laser backscattering at the ILC, should be explored with the same accuracy as the production in e^+e^- annihilation. Likewise, top threshold dynamics also governs associated top-pair production processes in specific kinematic end-point regions, such as $e^+e^-{\to}t\bar{t}H$ in the limit of large Higgs energy. The importance of the top threshold region might also be systematically explored in the framework of hadron collisions. These threshold effects are not important at the present level of accuracy, but they could become relevant at the LHC where top pairs will be produced with very high statistics.

From the beginning of Linear Collider studies more than 10 years ago, a number of experimental studies analysing the principle feasibility of top threshold measurements have been carried out. But only recently were machine-specific and more subtle effects such as the influence of uncertainties in measurements of the luminosity spectrum considered and found to be very important. After the recent technology decision for the ILC, such design-dependent studies need to be driven further to fully explore the potential of threshold measurements and to derive the optimal scan strategy. The most important missing tool, however, is a fully implemented top threshold event generator. This endeavour will be enormous, since such a generator will have to describe production, propagation, and the decay of quasi-bound top quarks in one single consistent framework. A close collaboration between experiment and theory will be crucial.

3 THE SUPERLAB

In recent years, the field of experimental high-energy physics has experienced a substantial reduction in the number of running experiments, together with the growth of large, expensive facilities used by an increasing number of physicists. In this respect, quarkonium physics is only one of the many physics studies competing for manpower and resources. In any of the experiments: CLEO-c, BES III, PANDA, Belle and BaBar at the B factories, and CDF and D0 at the Tevatron, the physics potential for quarkonia is many times larger than the analyses that are likely to actually be made. Because of this, many physics opportunities are lost. Heavy quarkonium studies will probably be a high-priority topic for BES III and possibly for PANDA. The currently running experiments, together with the BES III and LHC experiments, are likely to yield in the next five years an increase by one to two orders of magnitude of the number of reconstructed heavy quarkonia.

Initiatives involving transversally the different experiments are needed, to sort priorities between the different analyses to be done on the datasets, and to provide, whenever needed, a guideline for the best possible usage of available luminosity. By thinking of future studies on heavy quarkonia as an ideal 'Quarkonium Superlab', the QWG aims at merging theoretical and experimental efforts in this subject in a more effective and constructive way.

Recently, heavy quarkonium discoveries and confirmations in different production mechanisms have been blossoming in a concerted way at all the accelerator facilities. The observation of the $\eta_c(2S)$ and the $X(3872)$ are cases in point. While the $\eta_c(2S)$ was first observed by Belle in B decay and double charm production, it was subsequently confirmed by CLEO and BaBar in $\gamma\gamma$ collisions. Similarly, the $X(3872)$ was discovered by Belle in B decay and subsequently confirmed by both CDF and D0 in high-energy $\mathrm{p\bar{p}}$ collisions at the Tevatron. Discoveries of the same state with different production mechanisms are very important in order to gain information on the nature of the state. The study of quarkonia production in high-energy, heavy-ion collisions, as a signature of the production of a deconfined state of QCD matter, started at CERN in 1986, and gave rise to one of the most exciting observations made in the field of experimental QCD thermodynamics. Here again, the comparison of heavy quarkonium production results in pp, $\mathrm{p\bar{p}}$, pA and AA collisions is crucial to have full control of the underlying physics mechanisms.

Future expectations on heavy quarkonium experiments may be grouped as follows:

- In the short term (2004–2006), dedicated measurements on charmonium systems, mainly above the open charm threshold will be performed by CLEO-c, by running at $\psi(3770)$ between 4 and 4.4 GeV. At the same time, the two asymmetric B factories are poised to reach a total $\sim$ 1000 fb^{-1} of data at the $\Upsilon(4S)$ resonance, yielding record samples of $\eta_c(1,2S)$, $X(3872)$ mesons with probably a few new surprises. The collider experiments CDF and D0 will likely accumulate about 20 times the data samples taken during Run I, and will hopefully shed new light on the issue of heavy quarkonium production and polarization. A precise determination of the mass of the B_c meson, done using exclusive $J/\psi\,\pi$ decays, will be available soon (see *Fermilab Today*, December 3, 2004). Results from the NA60 experiment at CERN and the STAR and PHENIX experiments at RHIC are expected to provide further evidence of QGP. With the expected significant increase in statistics of the upgraded HERA collider, it might be possible to study inelastic photoproduction of bottomonium states for the first time, with the caveat that production rates of Υ resonances are suppressed by more than two orders of magnitude compared with the J/ψ.

- In the mid term (2007–2009), high-precision results are expected from the CLEO-c run at the J/ψ, and hopefully at the $\psi(2S)$, as recommended by the QWG. In the meantime, the fully upgraded BES III detector will take over the precision studies of charmonium started by CLEO-c. BES III could run on higher ψ resonances, high above the $D\bar{D}$ threshold and with high enough statistics to produce the higher P, D states via transitions from the ψ's. While the two running Tevatron experiments will complete their period of data taking, reaching total final samples of about 16 fb^{-1}, CERN will return to the scene in 2008, when the first beams are expected to circulate in the LHC accelerator. The first period of data taking, at low luminosity, will be very important to establish the physics potential of the ATLAS, CMS and LHCb experiments on heavy quarkonium production and B_c studies. Later, three experiments will be able to study quarkonia production in heavy-ion collisions at the LHC: ALICE, CMS and ATLAS. ALICE will measure the charmonia states through their decay into electron and muon pairs. Before the LHC start-up, the CERN experiment COMPASS also has the possiblility of obtaining new information on the doubly charmed baryons discovered by SELEX at FNAL. At CEBAF, high-intensity 9 GeV photon beams will allow the study of the J/ψ photoproduction mechanism at low energy.
  The future of the asymmetric B factories is unclear at present. If at least one of the two facilities increases its luminosity to become a super B factory, a large number of charmonium measurements will be within reach, and even the simple ISR production mechanism will yield record samples of $\Upsilon(1,2,3S)$ decays. A promising opportunity, recommended by the QWG, is to turn one of the two asymmetric B factories into an $\Upsilon(1,2,3S)$ factory during the last fraction of its running period. There is considerable $b\bar{b}$ physics that remains to be done. A few examples are: $\eta_b(n^1S_0)$ searches using M1 radiative transitions from the $\Upsilon(n^3S_1)$ states, h_b searches via hadronic transitions $\Upsilon(3S)\to h_b+\pi^0\to\eta_b+\gamma+\pi^0$ or $\Upsilon(3S)\to h_b+\pi\pi\to\eta_b+\gamma+\pi\pi$, and measuring radiative and hadronic transitions in the $b\bar{b}$ system.
- In the long term (2010 and beyond), PANDA at GSI offers the opportunity to study many charmonium states with non 1^{--} quantum numbers and can challenge BES III on high-statistic studies of the narrow charmonium states. Given the huge yields of heavy quarkonia expected from LHC experiments when running at full luminosity, the main problem will be the choice of high-priority physics cases and the main challenge will come from the need to keep trigger rates under control. At the same time the BTeV experiment at Tevatron will challenge LHCb on B_c physics in the forward region. Finally, the ILC, in the next decade, will test NRQCD at $t\bar{t}$ threshold, as well as a number of still unpredicted future hot issues in heavy quarkonium physics.