Future experiments

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The contribution discusses future experiments in hadron spectroscopy. It presents the physics motivation and the tools, i.e. the accelerators and the detectors. A review of the status of the relevant projects, Belle-II/SuperKEKB at KEK, SuperB in Italy, PANDA at FAIR, and CLAS12 and GlueX at JLAB, is also given.

1 Introduction

A substantial increase in the size of data samples available for searches of exotic hadronic states is expected in the next ten years. In what follows we shall discuss these future experiments in hadron spectroscopy. We will present the physics motivation and the tools, i.e. the accelerators and the detectors, and we will review the status of the relevant projects, Belle-II and SuperKEKB at KEK, SuperB in Italy, PANDA at FAIR, and CLAS12 and GlueX at JLAB.

2 Super B factories: Belle-II/SuperKEKB and SuperB

The two B factories, PEP-II with BaBar and KEKB with Belle, have been a real success story. They were built with the primary goal of measuring CP violation in the B system. From the discovery of large CP violation in 2001, the B factory results evolved into a precision measurement of the CP violation parameter $\sin 2\phi_1$ [1–3]. The constraints from measurements of angles and sides of the unitarity triangle show a remarkable agreement [4], which significantly contributed to the 2008 Nobel prize awarded to Kobayashi and Maskawa. The two B factories also studied numerous new phenomena, and, last but not least, observed a long list of new hadrons, some of which do not seem to fit into the standard meson and baryon schemes. All this was only possible because of the fantastic performance of the accelerators, much beyond their design values. In the KEKB case, the peak luminosity reached a world record value of $2.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, exceeding the design value by a factor

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of more than two. The two collaborations have accumulated data samples corresponding to integrated luminosities of 0.557 ab^{-1} (BaBar) and 1.041 ab^{-1} (Belle).

While B factories were built to check whether the SM with the CKM matrix is correct, the next generation of B factories (so called Super B factories) will search for departures from the Standard model. For this task, a $\approx$50 times larger data sample is needed [5], corresponding to an integrated luminosity of 50-75 ab^{-1}. Two recent publications summarize the physics potential of a super B factory, one prepared by Belle-II authors and guests [6], and the other by SuperB collaborators and guests [7]. To summarize, there is a good chance to see new phenomena, such as CP violation in B decays from new physics sources, or lepton flavor violation in τ decays. Needless to say that with such a large data sample there are many more topics to explore, including searches for new and exotic hadrons, and investigation of their properties.

Accelerators

To arrive at a $\approx$50 times larger data sample, a substantial upgrade of the B factory accelerator complex is required, leading to a 40 times larger peak luminosity. There are two super B factory projects under way. The first one, Belle II at SuperKEKB, foresees a substantial redesign of elements of the existing KEKB accelerator complex while retaining the same tunnel and related infrastructure. To increase the luminosity by a factor of 40, the plan is to modestly increase the current (by a factor of 2) with respect to the KEKB values, and dramatically shrink the beam size at the collision point, while the beam beam parameter is kept at the KEKB value (Table 1). In this 'nano-beam' scheme which was invented by Pantaleo Raimondi for the Italian SuperB project [8], the beams collide at a rather large angle of 83 mrad (compared to 22 mrad in KEKB). In addition, a lower beam asymmetry of 7 GeV and 4 GeV instead of 8 GeV and 3.5 GeV is needed to reduce the beam losses due to Touschek scattering in the lower energy beam. The modifications of the KEKB complex include: improvements in electron injection, a new positron target and damping ring, redesign of the lattices of the low energy (LER) and high energy (HER) rings, replacing short dipoles with longer ones (LER), installing TiN-coated beam pipe with ante-chambers, modifications of the RF system, and a completely redesigned interaction region [9].

Another approach to the design of a super B factory will be exploited in the Italian SuperB project [10]. Here it is foreseen that a new tunnel will be built (Fig. 1) at the campus of the Tor Vergata University, a few kilometers northwest of Frascati. Parts of the beam elements of PEP-II will be reused in the accelerator construction. In addition to the nano-beam scheme (Table 1), an essential feature of the SuperB accelerator is the crab waist collision of two beams in which special sextupoles will be used close to the interaction region to maximize the overlap of the two beams. This scheme was successfully tested at the DAΦNE ring by Pantaleo Raimondi and his team [11]. The SuperB accelerator is designed in such a way that it can be modified to run at the $\psi(3770)$ resonance close to charm threshold, where pairs of D^0 mesons are produced in a coherent $L = 1$ state [7].

	SuperKEKB		SuperB		
	LER (e^+)	HER (e^-)	LER (e^-)	HER (e^+)	
Energy	4.0	7.0	4.18	6.7	GeV
Half crossing angle	41.5		33		mrad
Horizontal emittance	3.2	4.3	1.82	1.97	nm
Emittance ratio	0.27	0.25	0.34	0.25	%
Beta functions at IP (x/y)	32 / 0.27	25 / 0.31	32 / 0.205	26 / 0.253	mm
Beam currents	3.6	2.6	1.82	1.97	A
Beam-beam parameter	0.0886	0.0830	0.0970	0.0971	
Luminosity	8×10^{35}		1×10^{36}		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Table 1: SuperKEKB and SuperB: parameters of the low energy (LER) and high energy (HER) accelerator rings.

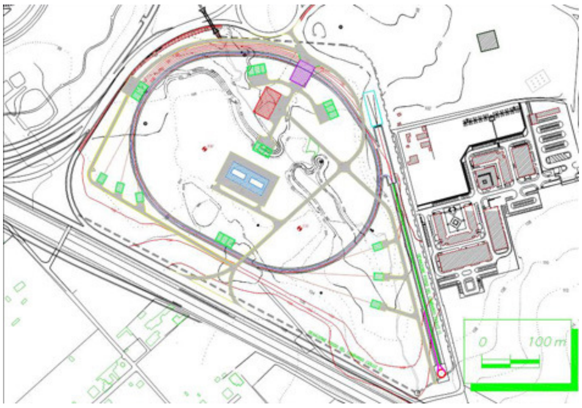

Figure 1: The new SuperB accelerator complex at Tor Vergata University site.

Detectors

The planned substantial increase in luminosity requires a careful design of the detectors. To maintain the excellent performance of the spectrometers, the critical issues will be to mitigate the effects of higher backgrounds (by a factor of 10 to 20), leading to an increase in occupancy and radiation damage, as well as fake hits and pile-up noise in the electromagnetic calorimeter. Higher event rates will require substantial modifications in the trigger scheme, DAQ and computing relative to the current experiments. In addition, improved hadron identification is needed, and similarly good (or better) hermeticity is required [9].

For the Belle-II detector (Fig. 2), the following solutions will be adopted [9]. The inner layers of the vertex detector will be replaced with a DEPFET pixel detector [12], the inner part of the main tracker (CDC, central drift chamber) will be replaced with a silicon strip detector, a better particle identification device will be used, the CsI(Tl) crystals of the end-

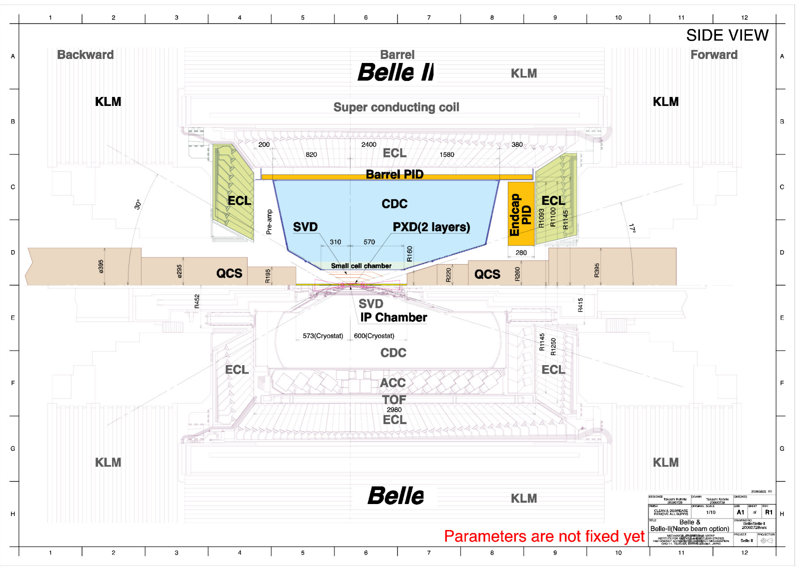

Figure 2: Upgraded Belle II spectrometer (top half) as compared to the present Belle detector (bottom half).

cap calorimeter will be replaced by pure CsI, the resistive plate chambers of the end-cap muon and K_L^0 detection system will be replaced by scintillator strips read out by SiPMs, and all components will be read-out by fast readout electronics and an improved computing system.

The hadron particle identification will be provided by a time-of-propagation (TOP) counter in the barrel part, and a RICH with a focusing aerogel radiator in the forward region of the spectrometer. The TOP counter [13] is a kind of DIRC counter [14] with quartz radiator bars in which the two dimensional information from a Cherenkov ring image is represented by the time of arrival and impact position of the Cherenkov photons at the photon detector. At a given momentum, the slower kaons (dotted in Fig. 3) emit Cherenkov photons at a smaller angle than pions; as a result, also their Cherenkov photons propagate longer along the quartz bar. Compared to the DIRC, the TOP counter construction is more compact, but requires photon detectors with single photon time resolution below 100 ps [13]. For the end-cap region a proximity focusing RICH with aerogel as radiator is being designed. The key issue in the performance of this type of RICH counter is to improve the Cherenkov angle resolution per track by increasing the number of detected photons. With a thicker radiator, the number of detected photons increases, but in a proximity focusing RICH the single photon resolution degrades because of the emission point uncertainty. However, this limitation can be overcome in a proximity focusing RICH with a non-homogeneous radiator [15], where one may achieve overlapping of the corresponding Cherenkov rings on the photon detector (Fig. 3). Both detectors are expected to considerably improve the

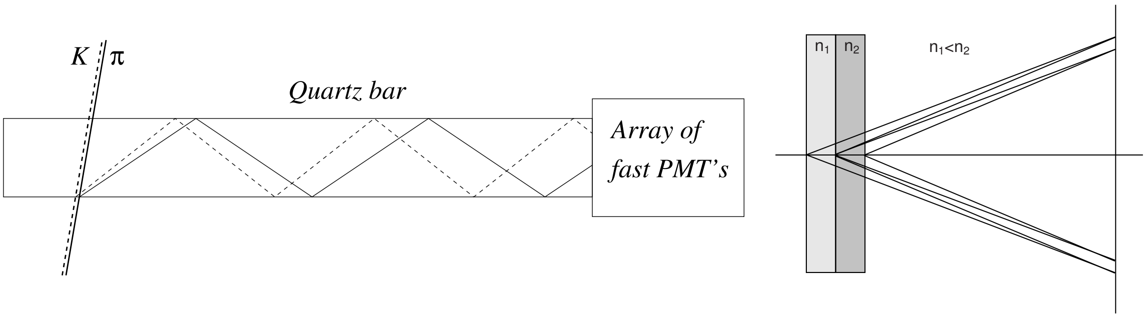

Figure 3: Belle-II PID systems: principle of operation of the TOP counter (left) and of the proximity focusing RICH with a nonhomogeneous aerogel radiator in the focusing configuration (right).

particle identification efficiency if compared to Belle; the end-cap RICH will provide a 4 σ π/K separation up to kinematic limits, and the barrel TOP counter will identify kaons with an efficiency exceeding 90% at a few percent pion fake probability.

The SuperB detector [16] will reuse several components of the BaBar spectrometer. In the baseline version two major changes are foreseen, replacing CsI(Tl) crystals in the forward calorimeter with LSO crystals, and a modification of the particle identification device, the DIRC counter. Options include a pixel detector layer, a RICH as the forward PID device and a veto electromagnetic calorimeter in the backward region to improve the hermeticity of the spectrometer.

In the new DIRC counter, the large stand-off box with single channel PMTs will be replaced by a compact focusing quartz block and multi-anode PMTs as photon sensors. By measuring the time of arrival of Cherenkov photons, the fast photon detectors will allow to correct for the chromatic error, i.e., variation of Cherenkov angle with wavelength [17]. The focusing DIRC counter is expected to extend the π/K separation range by improving the angular resolution by about 10%. At the same time, the order-of-magnitude lower mass of the expansion volume will considerably reduce the level of beam induced backgrounds.

Status of the projects

The SuperKEKB/Belle-II project has received initial construction funding in 2010 for the positron damping ring, and with the Japanese 'Very Advanced Research Support Program' a sizable fraction of funds for the main ring upgrade (exceeding 100 MUSD) for the period 2010-2012. KEK also managed to secure additional funds to complete the construction as scheduled, i.e., start the SuperKEKB commissioning in the autumn of 2014, and start data taking in 2015. It is expected that by 2017 the first 5 ab^{-1} of data will be collected, and the full data sample of 50 ab^{-1} will be reached in 2020/2021.

The SuperB project is the first in the list of 'flagship projects' of the new Italian national research plan over the next few years. The Italian government has delivered an initial funding for 2010 as a part of a multi-annual funding program. The site has been chosen at the Tor Vergata University campus, a few kilometers northwest of the Frascati lab. The aim of the project is to accumulate 75 ab^{-1} on a time scale similar to SuperKEKB/Belle-II.

3 PANDA at FAIR

At the High-Energy Storage Ring (HESR) of the FAIR facility at GSI, the PANDA experiment is being prepared with the aim to study meson spectroscopy (excited D mesons, charmonia and charmonium like states, search for hybrids, tetraquarks, molecular states), charmed and multi-strange baryon spectroscopy, electromagnetic processes ($p\overline{p} \to e^+e^-$, $p\overline{p} \to \gamma\gamma$, Drell-Yan processes), properties of single and double hypernuclei, and properties of hadrons in nuclear matter [18]. Anti-protons as a probe are interesting because their interactions are rich with gluons, and the system allows to reach all states with fermion-antifermion quantum numbers, including states with high orbital angular momenta. Another feature of the experiment is a very high mass resolution in formation reactions.

The detector (Fig. 4) is required to cover the full solid angle, operate at high rates ($2 \cdot 10^7$ annihilations/s), allow for good particle identification ($\gamma, e, \mu, \pi, K, p$) and momentum resolution ($\approx 1\%$), vertexing (reconstruction of D, K^0_S, Λ), have an efficient software trigger (for e, μ, K, D, Λ) and stand a raw data rate exceeding 200 GB/s.

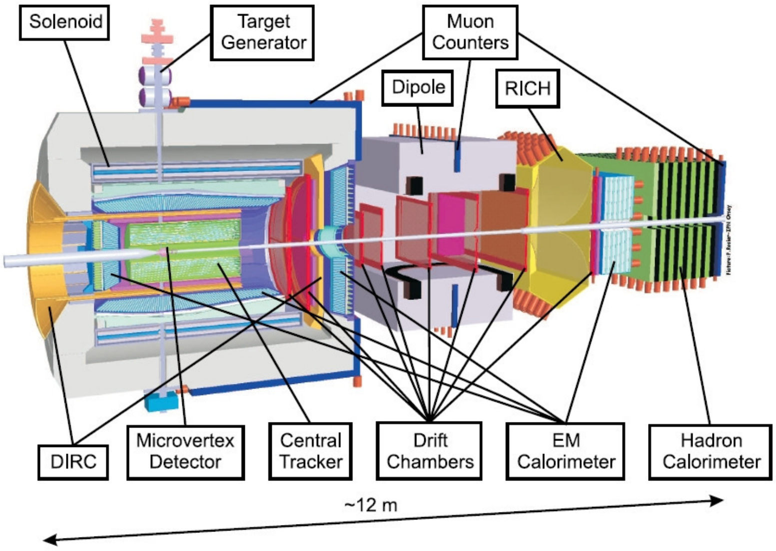

Figure 4: The PANDA spectrometer.

Antiprotons will impinge onto an internal target, which can be either in form of pellets (frozen droplets) or as a cluster jet (nanoparticles). The vertex detector will be a combination of a pixel detector with 10 million channels and a micro-strip detector with 70,000 strips.

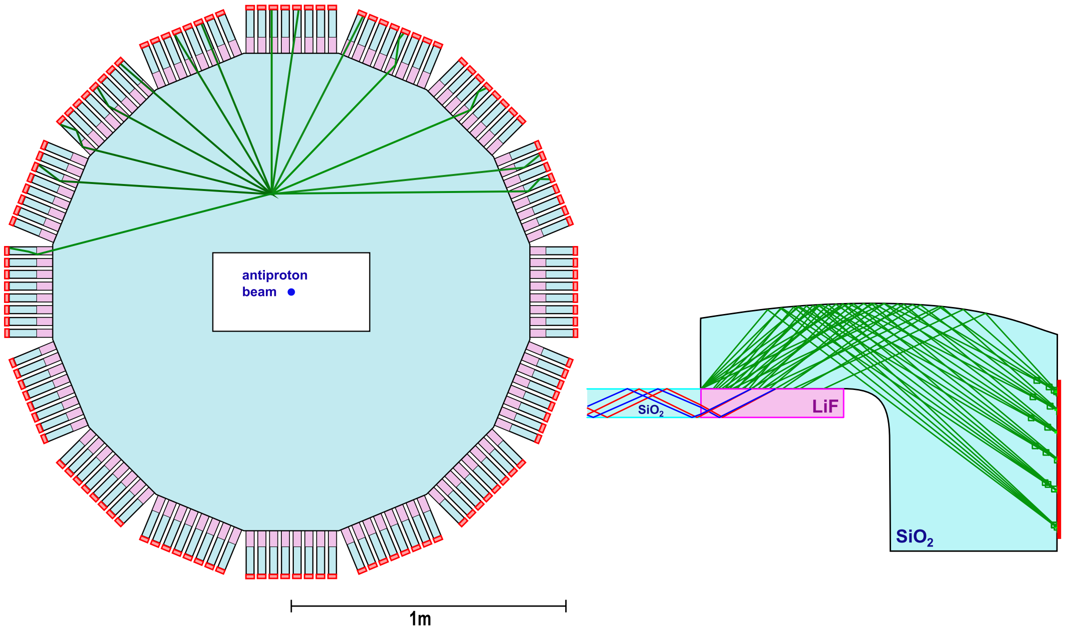

Figure 5: The forward DIRC counter of the PANDA experiment, a polygonal quartz disk read out through an array of focusing elements [20].

For charged hadron identification, two DIRC-like counters are considered [19]. For the barrel part, a focusing version will be used with a lens as a focusing element at the exit of the bar. In the forward direction, a novel type of DIRC device is being designed [20] with a 2 cm thick polygonal disc radiator made of quartz (Fig. 5). In this case Cherenkov photons are propagated to the sides of the disc, where they are focused with specially formed quartz pieces onto the photon detectors. An intermediate LiF piece is used to correct for the dispersion.

For an efficient high rate detection of gamma rays and neutral pions, a fast $PbWO_4$ based calorimeter will be used [21]. The counter will employ the second generation $PbWO_4$ crystals with a two times higher yield if compared to the $PbWO_4$ calorimeter of the CMS experiment. A further considerable increase in yield is expected from running the calorimeter at -25^0 C. As photosensors, large area APDs (14 x 7 mm^2) will be employed.

4 CLAS12 and GlueX

Considerable upgrade of the accelerator and of the detectors is underway at the Jefferson Lab. The CLAS detector [22] in Hall B is being upgraded to work at a higher luminosity (10^{35} cm^{-2}s^{-1}) and with an increased solid angle and momentum coverage, with the aim to study nucleon structure via generalized parton distributions [23]. Among the new features of the CLAS12 detector are an upgraded PID system (for separation of e/π, $\pi/K/p$, γ/π^0)

and an improved vertex detector for identification of weakly decaying strange baryons. The forward PID system upgrade involves a new high threshold Cherenkov counter, an improved TOF system, a higher granularity calorimeter and possibly a RICH counter [24]. The construction of the new CLAS12 detector is on schedule for the installation starting in October 2012.

The GlueX experiment is being constructed in the new experimental Hall D with the aim to search for exotic hybrids in the interaction of 9 GeV tagged polarized photons [25]. The detector construction is well underway, it is on-track for the first beam to be delivered in 2014.

5 Summary

Several new projects are under preparation with a potential to considerably improve our understanding of hadron physics. A major upgrade has started at KEK to construct the SuperKEKB accelerator and the Belle-II detector, and be ready for data taking by 2015. The SuperB project in Italy foresees building a new tunnel, reusing and upgrading the PEP-II accelerator and the BaBar detector. For the PANDA detector, a technical design report is expectd by the end of 2011, and installation in 2016/17. At JLAB, CLAS12 is on schedule for the installation in fall of 2012, and the GlueX experiment is on-track for the first beam in 2014. We can therefore expect a new, exciting era of discoveries in hadron physics.

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