FUTURE PLANS FOR e^+e^- FACTORIES

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Abstract

In the last decade luminosities of lepton colliders have greatly risen. There are several ingredients of the success: the progress in the handling of high currents and multibunch regimes, in the beam-beam interaction limits understanding, in particle dynamics simulation codes, in the diagnostic systems to control beam sizes and orbits, in the background shielding.

Now is time to go further in the high luminosity frontiers: experiments are asking for more precision measurements, and the accelerator community is facing projects where the increase of luminosity by orders of magnitude is conceivable. New ideas, main upgrades and plans in the factories presently in operation around the world are the subject of this paper.

INTRODUCTION

The frontier of high luminosity does not coincide with the high energy one. Non-search colliders dedicated to precision physics have in last decade advanced the luminosity by one order of magnitude. The great success of B-factories which in few years have reached their design goals has demonstrated to the physics community the possibility of reaching in their experiments unprecedented precisions approaching theory limits.

For sake of discussion, the diagram of the luminosity, *L,* versus energies, *E*, can be divided in three zones (see Fig.1): in the first zone the energy increase is privileged for new particles production, reaching the maximum with LEP; the corresponding luminosity is continuously improved, both for its dependence on energy and for the advances in technologies and collision physics. Beyond LEP linear colliders will supplant circular ones; VLLC should double LEP energy but at the price of one order of magnitude in ring size. In the second zone there are the present factories, with luminosities one order of magnitude larger than the previous ones at the same intermediate energies. The third zone represents the future, in which upgrades by a factor 10 seem reachable with present technologies, while higher upgrades are subjected to R&D progress.

The physics community asks for higher fluxes of particles at the intermediate energies[1-4]. The annihilation production cross section in e^+e^- collisions is proportional to the inverse square of the energy, and the necessary integrated luminosity scales accordingly:

$$\int L \propto \frac{1}{\sigma} \propto E^2 \qquad (1)$$

Table I shows the approximate integrated luminosities already collected by all experiments in the energy range between the Φ and the B, and the luminosities requested for competitive experiments in the LHC era. There is a long path before reaching the wanted specifications. A review of the plans of e^+e^- factories according to their energy is described in the paper.

Table 1 - Collected and requested integrated luminosities

	E_{cm} (GeV)	logged ∫L	requested ∫L
Beauty	10.6	~ 300fb^{-1}	10 ab^{-1}
τ-charm	3.9	< 1 fb^{-1}	>100 fb^{-1}
light quarks	1-2	< 100pb^{-1}	500 pb^{-1}
Φ	1	< 1 fb^{-1}	100 fb^{-1}

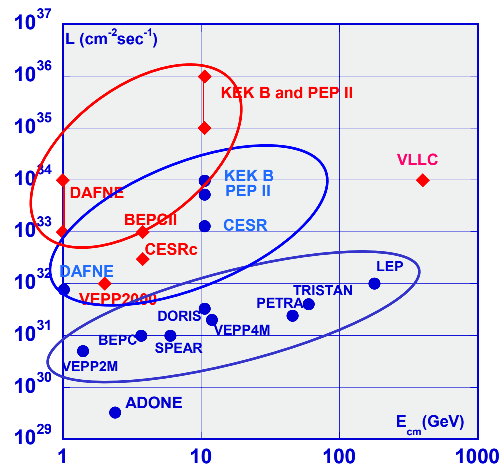

Figure 1: Luminosity versus energy in lepton circular colliders. Past and present results (blue dots), future projects and designs (red diamonds)

LUMINOSITY CONSIDERATIONS

Storing high currents in closely spaced bunches and squeezing as much as possible beam sizes translates in luminosity increase, according to:

$$L = \frac{f_{coll}}{4\pi} \frac{N^+ N^-}{\sigma_x^* \sigma_y^*} \qquad (2)$$

The collision frequency, f_{coll}, the bunch populations, N^{+-}, the transverse beam sizes, $\sigma_{x,y}^*$, apparently independent, are strongly related by the beam-beam interaction and by collective effects. According to the collider regime, L can be written in terms of the characteristic beam-beam tune shift parameters, $\xi_{x,y}$, the emittances, $\varepsilon_{x,y}$, the betatron functions at the IP, $\beta_{x,y}^*$: when the reachable $\xi_{x,y}$ is the most severe luminosity limitation, L for flat beams is usually expressed as:

$$L = \frac{\pi f_{coll}}{r_o^2} \frac{\gamma^2 \varepsilon_x}{\beta_y^*} \xi_x \xi_y \qquad (3)$$

which compared with eq.1 shows the same dependence with the energy.

High currents

All high current issues have been addressed by the collider physicists together with the synchrotron radiation community. The understanding and control of machine impedances has increased the threshold instabilities in all high brilliance rings. The present generation of bunch by bunch feedbacks for multibunch operation, first tested in synchrotron light sources[5], is operational in all factories and is also a powerful diagnostic tool.

Ion trapping in electron rings, already known when first generation factories were designed, is controlled by gaps in bunch trains and/or ion clearing electrodes. Electron cloud instability (ECI) in e^+ rings, which was first observed at the KEK Photon Factory in 1995, is one of the main limiting effects in increasing the currents in B-factories. The photoemission and multipacting creates additional loads to vacuum and cryogenic systems, and the emittance blow-up constitutes a serious limitation to luminosity. Solenoidal windings are the present cure of the instability; new vacuum chamber designs are being developed, in collaboration with the hadron collider community, also threatened by the ECI.

Besides instabilities induced by collective effects, high currents are responsible for intense photon fluxes on the vacuum chambers and high loads on rf system; vacuum, cooling and rf technology developments are always correlated with every achievement in the luminosity scale[6].

Beam-beam

Beam-beam effect limits the single bunch luminosity. All present factories, but VEPP2000, are based on the multibunch regime. Crossing angle is now better understood. The Piwinski factor relating the crossing angle θ with the characteristic dimensions of the bunch:

$$\phi = \theta \frac{\sigma_L}{\sigma_x} \qquad (4)$$

has reached values that 10 years ago were considered dangerous source of synchrobetatron resonances.

Small values of β_y* are obtained thanks to magnet technology, which has developed small dimension - high gradient quadrupoles to be placed near IPs.

Careful tuning of single ring working point, dynamic aperture optimisation, possibility of coupling corrections up to very small values (coupling of the order of 0.1% have been obtained), are all dowels of the puzzle for obtaining high beam-beam tune shifts.

Background

Background rejection from experiments is one of the key points of any collider. Continuous optimization of background is done routinely at all present factories, and adding masks, collimators, and cooling is envisaged in next future in all of them. In the lower energy factories, where background is dominated by Touschek losses, the lattice configuration of the whole ring is optimized for minimisation of losses in the detector areas.

Lifetime and injection

Average to peak luminosities ratios depend on lifetime and injection rates. Lifetimes decrease as currents are raised due to beam-gas scattering and Touschek effect, this last becoming predominant in low-energy rings. At extremely high luminosity the annihilation process becomes the predominant particle loss effect. Presently the beam lifetimes are of the order of hours, but will be shortened to few minutes in the super-factories regime. Only continuous injection will allow the operation of the colliders, and background at injection becomes one the key-point to be solved.

BEAUTY FACTORIES

The two B-factories, KEK-B and PEP II, on the opposite sides of the Pacific Ocean, have reached their design values in a very short time, compared to the scale of accelerator history, despite these values were considered challenging when in the 90's the projects were conceived. During the preparation of this manuscript I have corrected the luminosity records several times.

CESR has also operated in this range of energy; this collider has shown along the years an increase in performances able to compete with the newer collider generations, and is now going towards lower energies. It kept for some time the record of luminosity and it can cover all the physics from the J/Ψ to the Beauty.

Both KEKB and PEPII plan upgrades for next two-three years, optimizing the existing systems to reach luminosities of few 10^{34}cm^{-2}sec^{-1}. Further steps on luminosity are being planned in a time scale of 10 years. Table 2 shows some of the main parameters for the future upgrades [7-8].

Table 2 - B factories from 10^{34} to 10^{36} cm^{-2}sec^{-1}

Collider	**KEK-B**		**PEP-II**		
	super	**hyper**	**next**	**super**	**hyper**
E + (GeV)	**3.5**	**3.5**	**3.1**	**3.5**	**3.5**
E - (GeV)	**8.0**	**8.0**	**9.0**	**8.0**	**8.0**
C (m)	**3016**	**3016**	**2199**	**2199**	**2199**
L $10^{34}cm^{-2}s^{-1}$	**10**	**40-100**	**2.5 - 4**	**20**	**100**
IPs	**1**	**1**	**1**	**1**	**1**
β* (m) (h)	**0.30**	**0.15**	**0.5**	**0.3**	**0.15**
β* (m) (v)	**0.003**	**0.003**	**0.0065**	**0.0037**	**0.0015**
ε (n rad) (h)	**33**	**33**	**44**	**44**	**44**
ε (n rad) (v)	**2**	**0.33**	**0.44**	**0.44**	**0.44**
θ (mrad)	**±15**	**0**	**0 -± 4**	**±10**	**±15**
ξ (h)	**0.068**	**0.1**	**0.08**	**0.10**	**0.10**
ξ (v)	**0.05**	**0.2**	**0.08**	**0.10**	**0.10**
N bunches	**5018**	**5018**	**1700**	**3400**	**7000**
I+ (A)	**9.4**	**17.2**	**4.5**	**11.0**	**10.3**
I - (A)	**4.1**	**7.8**	**2.0**	**4.8**	**2.35**
f_{RF} ***(MHz)***	**509**	**509**	**476**	**476**	**952**

PEP-II upgrades

The goal of reaching L of the order of 10^{34} $cm^{-2}sec^{-1}$ by 2005 is based on adding rf stations in order to increase currents and number of bunches. Shorter bunches, and therefore smaller β_y^* will be possible. An upgrade of the longitudinal feedback system with new electronics and DAFNE-like kicker[9] will increase the effectiveness of the system. Higher injection rate, correlated with added collimators to shield injection background will pay on the integrated luminosity. Solenoidal windings for ECI together with increased cooling should help in the current increase.

The same philosophy is foreseen up to 2008, but pushing parameters to more limiting values: β_y^* will be decreased by 50% by moving quadrupoles closer to IP, a small crossing angle in the new IR will be introduced, higher currents will be based on the feedback system upgrade to go to 2-bucket spacing. All these actions should push luminosities up to 2-4 10^{34} $cm^{-2}sec^{-1}$. $\xi_{x,y}$ of 0.08 are considered achievable.

Higher luminosity considerations will be of course related to the achievements obtained at that point; with the today know-how, the idea is to increase the collision frequency by filling all buckets, without increasing bunch currents, together with a larger crossing angle and smaller betas at IP. The total current will be doubled and to save wall power the energy asymmetry will be diminished. Tune shifts will be 0.1 and L of the order of $10^{35}cm^{-2}sec^{-1}$.

The main upgrade for a further increase is again doubling the number of bunches by changing f_{rf} to 950 MHz, and still increasing the crossing angle. With the same b-b tune shift and slighly lower currents per bunch the total L could reach values of 10^{36} $cm^{-2}sec^{-1}$. R&D on the rf cavity and related systems is already in progress.

KEK-B upgrades

The Japanese B-factory has recently exceeded the 10^{34} $cm^{-2}sec^{-1}$ goal, the maximum luminosity ever reached. The upgrades for a factor 10 are based on an increase of the bunch number by a factor 4, together with an increase of the bunch current, lowering β_y^* by a factor 2 and increasing the crossing angle. An increase of the emittance keeps the b-b tune shifts equal to the present ones. The main challenge are the high current effects; the rf system will be upgraded and SC rf cavities will be added. A beam-energy switch is envisaged, so that e^+ are stored in the HER with lower currents to weaken the ECI effect. An upgrade of the injector is thus being studied to accelerate positrons up to 8 GeV. Intensive R&D on vacuum chamber design, with antichambers and special rf shields is in progress, and prototypes are being constructed to be installed soon in the collider for first tests.

Crab crossing and head-on collisions are the key point to reach 10^{36} $cm^{-2}sec^{-1}$: higher b-b tune shifts by doubling the current per bunch and no reduction factor due to crossing angle are predicted by simulations. The very high ξ_y is obtained also by lowering the coupling.

TAU-CHARM FACTORIES

BEPCII, CESRc

CESR is moving toward lower energies. Wigglers are added to increase radiation damping, and this is the main feature for the new configuration. The first wiggler has just been installed and commissioned. Other 12-14 wigglers will be installed in one year and CESR will run until 2008 at three energies between 3.1 and 4.1 GeV.

In China BEPC will be upgraded to become the first completely dedicated tau-charm factory, still mantaining the synchotron radiation production. Its design is based on the double ring scheme, with energies ranging between 1.5 and 2.5GeV per beam, optimized at 1.89 GeV. An inner ring will be installed inside the old one, so that each beam will travel in half outer ring and half inner one. Superconducting cavities fitting the bunch length requirements will be installed. The production began in 2002 and commissioning is foreseen for 2006.

Table 3 shows the design values of the Chinese τ-charm factory[10] together with the CESR-c[11] parameters at the same energy.

Table 3 - Tau charm factories

Collider	CESRc	BEPC II
status	operating	in construction
E (GeV)	1.88	1.89
C (m)	768	237.5
L (10^{32} $cm^{-2}s^{-1}$)	3	10
IPs	1	1
β* (m) (h / v)	0.7/ 0.011	1 / .015
ε (μ rad) (h / v)	0.22	0.17 / 0.002
θ (mrad)	± 2.8	± 11
ϕ (rad)	0.07	0.4
σ_z (cm)	1.0	1.5
N_b (10^{10})	6.4	4.8
ξ (h / v)	0.03 / 0.03	0.04 / 0.04
N bunches	45	93
I (A)	.18	0.91
f_{RF} (MHz)	500.0	499.8
V (MV)	10	1.5

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LIGHT QUARKS FACTORIES

Physics at energies between the ϕ and τ have been covered during last years by VEPP-2M (shut down in 2000) and BEPC colliders. The interest for this energy range had produced the proposal for PEP-N[12]. Now a collider, innovative in its design and concepts, is in construction: VEPP2000. At this energy range the interesting physics needs moderate integrated luminosities, as shown in Table 1.

VEPP2000

A 2 GeV collider (from there the 2000 in the name), whose design is based on the concept of round colliding beams, is being constructed in Novosibirsk[13], after the shutdown of VEPP-2M three years ago. This is a very important step in the beam-beam interaction understanding. The expected b-b tune shift is twice smaller than the corresponding flat-beam one with the same particle density, thus predicting a single bunch luminosity of $10^{32}cm^{-2}sec^{-1}$[14].

The collider can be operated also with flat beams and at energies ranging from 500 Mev to 1 GeV per beam. Its compact design is based on very high field normal conducting dipoles (2.4T) and houses two experiments in the two simmetric Interaction Regions. Focusing in the two interaction regions is performed by SC solenoids, which also rotate by $\pi/2$ the planes of betatron oscillations, thus creating emittance in both transverse modes. Dynamic aperture is challenging due to the high chromaticity and beam sizes on both planes.

Dipoles are bein installed, solenoids are in the construction phase and first beam is foreseen in one year from now.

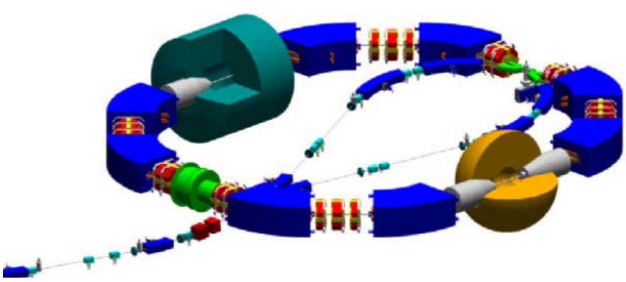

Fig. 2 - View of the VEPP-2000 collider

Table 4 - Light quarks factories

Collider	VEPP2000	DAFNE 2
status	**in construction**	**design study**
E (GeV)	**1.**	**1.**
C (m)	**24**	**97**
L (10^{32} $cm^{-2}s^{-1}$)	**1**	**1**
IPs	**2**	**1**
β^* ***(m) (h / v)***	**0.1 / 0.1**	**1.5 / 0.025**
ε (μ ***rad) (h / v)***	**0.136 / 0.136**	**0.5 / 0.0025**
θ ***(mrad)***	**0**	**±15**
ϕ ***(rad)(Piw)***	**0**	**0.26**
σ_z ***(cm)***	**3**	**1.1**
N_b (10^{10})	**10**	**3**
ξ ***(h / v)***	**0.1 / 0.1**	**0.014 / 0.024**
N bunches	**1**	**30**
I (A)	**0.20**	**0.45**
f_{RF} ***(MHz)***	**172**	**368.3**
V (MV)	**0.12**	**0.25**

DAFNE2

DAΦNE has been constructed to operate at the Φ resonance. Some of the systems are dimensioned to operate also at higher energies. It is presently under discussion which will be the future of the collider. One of the possibilities is to increase the energy by a factor of two [15]. The project is named DAFNE2, where "F" stands for Frascati and "2" for the E_{cm}. No crucial issues from the accelerator physics point of view are envisaged. The main hardware modifications concern dipoles, splitter magnets, and low-beta quadrupoles, while rf and vacuum systems are already dimensioned for the high energy, with a lower beam current. The main parameters are given in table 4 together with those of VEPP2000 for comparison.

Φ-FACTORIES

DAΦNE is the only Φ-Factory presently in operation. VEPP2000 can be operated also at the Φ resonance, with of course a lower luminosity than the optimum one.

DAΦNE

By the end of 2005 all the current physics programs are expected to be almost completed, with an overall delivered integrated luminosity in excess of $3fb^{-1}$ and luminosities higher than $10^{32}cm^{-2}sec^{-1}$. Operation is done in time sharing between the two experiments, since simultaneous collisions at both IPs are critical. After the DEAR completion [16], during the 2003 shutdown the third experiment, FINUDA, is being installed, and will share the collider with KLOE during the next few years. Crossing angle will be increased with respect to design values, by changing the low beta configuration from FDF to DF. Both β_x^* and β_y^* will be lowered. Sextupole components are being added to a family of quadrupoles for dynamic aperture optimization. Damaged ion clearing electrodes are being replaced.

The interest for values of the luminosity larger by a factor 10[4] than the design ones has lead to the study of possible new designs of the factory.

Experience has shown that powerful radiation damping is needed; presently in DAΦNE natural damping is increased by a factor two by the wigglers, which on one hand increase achievable b-b tune shifts, but on the other one limit the dynamic aperture. Simulations [17] show that roughly a factor 10 on τ_d would allow an increase of the b-b tune shifts by a factor of two. A preliminary design of a ϕ-factory is being studied. The parameters are shown in Table 4, together with those which are foreseen for next future in the present configuration. The preliminary design, named DAΦNE-w[18], is based on cells where positive and negative normal conducting bendings alternate, with a net positive bending angle and an increase in radiation damping. The layout and the vacuum chamber design are different from the present one. Special care is dedicated to optimise the dynamic aperture, and is mainly dominated by the non linear terms arising from the wiggling bendings. Increase of the average luminosity is expected from continuous injection scheme, based on the separation of the now shared e^+ and e- injection transfer lines.

Table 4 - ϕ factories

Collider	DAΦNE	DAΦNE w
status	until 2005	design study
E (GeV)	.51	.51
C (m)	97	80
L (10^{32} $cm^{-2}s^{-1}$)	> 1	> 10
IPs	1	1
β^* (m) (h / v)	1 / 0.025	0.5 / 0.01
ε (μ rad) (h / v)	0.6 / 0.006	0.2 / 0.001
θ (mrad)	± 16	± 15
ϕ (rad)	0.39	0.57
σ_z (cm)	2	1.2
N_b (10^{10})	3.6	3.5
ξ (h / v)	0.027 / 0.043	.079 / 0.070
N bunches	100	95
I (A)	1.8	2.0
f_{RF} (MHz)	368.3	369
V (MV)	0.2	0. 5

NEW IDEAS

New, original, sometimes daring ideas for increasing the particle production are arising. I will mention some of them.

Collision with four-beam scheme, which was tested in DORIS and DCI, with neutralization of the charge between e+ and e^-, and no b-b linear tune shift, has been revisited by the KEKB group[7] .

Collide beams of higher energies with large crossing angles, so that E_{cm} corresponds to the Φ, is being investigated for DAΦNE: two 1.5 GeV rings colliding at 140° (meaning that beams travel in the same direction), will produce Φ's with a boost such that K_s decays in length of 1m, while K_L can be detected at distances up to 10 m, simplifying the problem of detector background shielding. The main advantage is the less critical behaviour of a higher energy ring from the point of view of beam lifetime and radiation damping. Luminosity and ξ behaviour with large crossing angle have been investigated[19]. The main disadvantage is the need of very short bunch. Introduction of a "longitudinal low beta" at the IP, so that the beam changes its length along the ring and is minimum at the IP, by tuning the R_{56} term along the ring, is being investigated.

Collide ring against linac is another idea being taken into consideration.

CONCLUSIONS

The next steps of the lepton factories are straightforward and consist in optimizing all the techniques developed during last ten years, expecting in all cases an increase in peak and integrated luminosity by about a factor 10. New ideas to push the luminosity values by another order of magnitude are being investigated. Round beam collisions will soon be tested at VEPP2000, answering to the question whether b-b tune shift limits can be raised. Fig.3 summarizes the foreseen timetable for the present factories in next future.

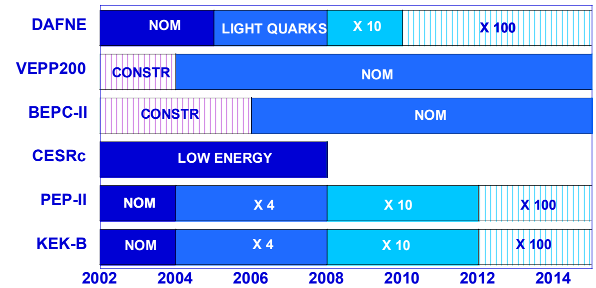

Fig. 3 - Timetable of foreseen factories future

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