TOWARDS HIGHER LUMINOSITIES IN B AND PHI FACTORIES

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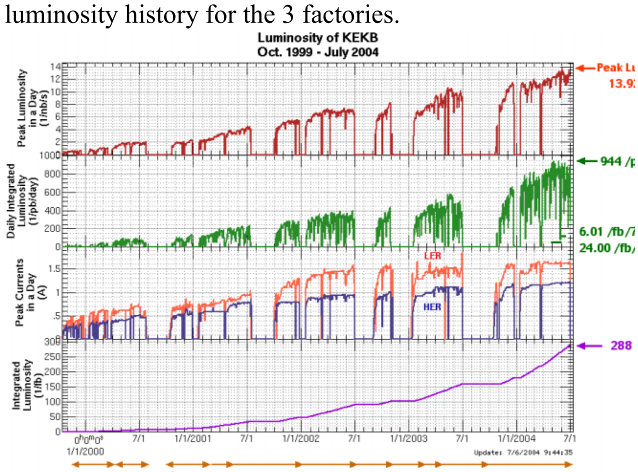
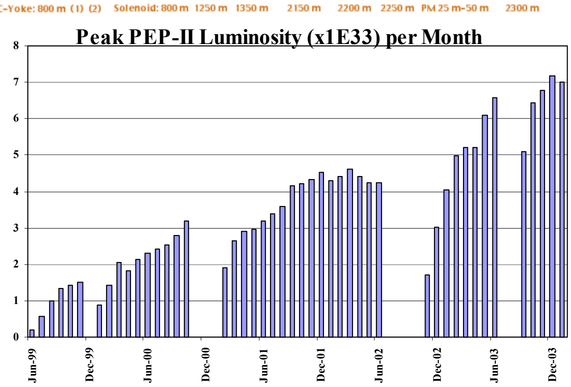
Abstract

A brief review of the performances of the existing Factories will be presented. Such machines have been proved extremely successful, for both particle and accelerator physics. To further extend their physics reach, several plans are under way to upgrade the existing colliders, in order to increase their luminosity up to an order of magnitude,. Will also be described several new schemes and ideas to realize full "Second Generation Factories" aimed at luminosities two order of magnitude higher then what achieved so far.

INTRODUCTION

The B and Phi factories began operations around 1999. Since then, the B factories (PEPII and KEK-B) have exceeded their design peak luminosity and greatly exceeded the expected integrated luminosity, whereas the DAFNE phi factory is still about a factor 5 below the design peak and total integrated luminosity. However it has to be pointed out that this is the only factory with two possible interaction regions, and already 3 different experiments have taken data. In particular the integrated luminosity requirement for DEAR [1] and FINUDA [2] have been met and these experiments have successfully completed their data taking. In Fig.1 is shown the luminosity history for the 3 factories.





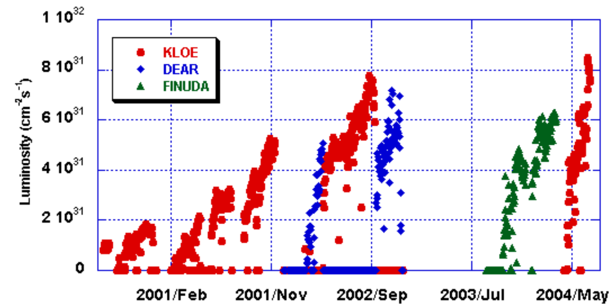


Fig. 1: Luminosity history for the B and PHI factories

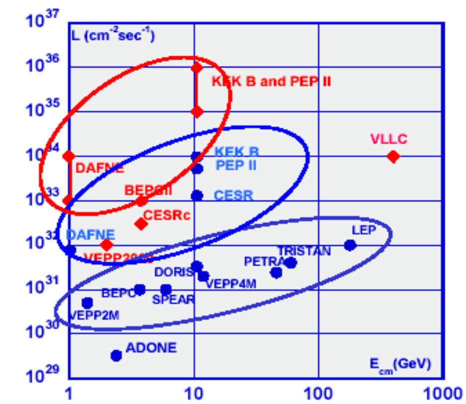


Fig. 2: Luminosity vs energy for "standard" colliders, factories and target for super-factories (red)

Five years of operations have proved extremely useful to understand all the important parameters to reach high luminosities. The accelerators have evolved through this period and have several significant differences with respect to the original design. The current parameters list is shown in tab.1. The acquired experience and know-how is driving all the near future upgrades and the design of the next generation factories.

Tab.1: Parameters set for the factories

	PEP-II	KEK	DAFNE	
LER energy	3.	3.5	0.51	GeV
HER energy	9.0	8.0	0.51	GeV
LER current	2.4	1.6	1.1	A
HER current	1.6	1.2	1.1	A
β_y^*	10.0	6.5	27	mm
β_x^*	25	60	250	cm
X emittance	50	20	600	nm-rad
Estimated σ_y^*	5.0	2.2	6.0	μm
Bunch spacing	1.26	2.4	1.6	m
Number of bunches	1317	1284	50	
Collision angle	0	22	24	mrads
Luminosity	9.2×10^{33}	13.9×10^{33}	$7.5*10^{31}$	$cm^{-2}\ sec^{-1}$

BEAM SIZES DECREASE

As shown in tab.1, KEK has been able to reach an higher luminosity with less beam current, thanks to a smaller β_y at the IP and a better coupling correction. During the years, all the machines have constantly improved the specific luminosity with an "adiabatic" reduction of β_y and vertical emittance.

The need to further decrease the vertical beam size and the effect of the parasitic crossings has driven a redesign of the interaction regions. Tab.2 shows the new parameters set for PEP-II and DAFNE.

PEP-II maintains the head-on collision scheme to avoid the luminosity reduction due to the crossing angle, that has been estimated to be about 40% for a 6mrad crossing angle. The main differences are in an increased separation at the first parasitic crossing thanks to the stronger IR bend and a lower β_y thanks to a stronger IR QD. The new design is still under study and should be implemented around year 2006 [3].

DAFNE goes from a QF-QD-QF triplet configuration to a more standard QD-QF. This allows a simultaneous reduction of β_x , β_y and the vertical chromaticity, together with an increase of the crossing angle. The effect of the parasitic crossings is greatly reduced, thus allowing for doubling the number of bunches. The price to pay is an increased luminosity reduction (of about 20%) due to the higher crossing angle. The new IR is already installed and operations with 100 bunches have just started last May

Tab.2: Parameters set for the short-term upgrades

	PEP-II	**DAFNE**	
LER energy	3.	0.51	GeV
HER energy	9.0	0.51	GeV
LER current >	3.6	1.5	A
HER current >	2.0	1.5	A
$\beta_y^* <$	7.0	19	mm
β_x^*	25	130	cm
X emittance	40	380	nm-rad
$\sigma_y^* <$	2.6	5.0	µm
Bunch spacing	1.26	0.8	m
Number of bunches	1700	100	
Collision angle	0	32	mrads
Luminosity>	30×10^{33}	$1.5*10^{32}$	$cm^{-2}\ sec^{-1}$

BEAM CURRENT GROWTH

The increase of the beam currents while preserving as much as possible the "low current" beam parameters and acceptable background level in the detectors has been very impressive.

The RF system plays an important rule for the high current and all the B-factories have upgraded the RF power the controls and the RF feedbacks several times. More RF stations will be installed in the near future to meet the higher currents goals The DAFNE RF system has been already dimensioned for currents above 3Amps and does not need any upgrade.

The requirements for the longitudinal and the transverse feedbacks becomes more and more demanding, in particular for DAFNE that now has the smaller bunch spacing and the smaller beam stiffness due to the lower operating energy.

The Electron Cloud Instability for the B-factories positron rings has been successfully damped with added solenoids. This instability has not been seen so far in DAFNE.

The collimation system has been upgraded as well with more and more collimators added in all the factories, several modifications have been implemented in the new IRs in order to further reduce the background from SR, vacuum scattering and Touschek (in DAFNE). So far the background requirements from the experiments have always been met, but it will be harder has the currents increase and the beam lifetimes decrease.

BUNCH LENGTH SHORTENING

The bunch length does not appear naturally in the luminosity equation, however since the machines do mostly operate in a vertical beam-beam limited regime, the luminosity is inversely proportional to the β_y. The minimum value for β_y is equal to the bunch length, for smaller values the hourglass effect causes a big loss in luminosity. Additional luminosity reduction comes from the crossing angle, that introduces synchro-betatron coupling and an additional increase of the horizontal size, since the projected beam size along the interaction region will be larger (Piwinski angle > 0). Finally the beam-beam effects in the vertical plane are enlarged by the crossing angle together with a finite bunch length. All these combined effects make the luminosity decrease faster then $1/\sigma_z$.

The current β_y for PEPII and KEKB are getting closer and closer to the bunch lengths, although the hourglass limit will not be exceeded in the mid-term upgrades. In DAFNE the limit has been already reached, since the microwave instability appears at very low bunch charge. At the operating currents the bunch is about 27mm long, causing a severe limit in the attainable luminosity. In this regime the RF voltage is a very weak parameter to squeeze to bunch. A possible solution to such problem is to change sign to the ring momentum compaction α_c. If α_c <0 the longitudinal wake field becomes focusing reducing the bunch length a low current. At higher currents it becomes overfocusing and the bunch starts to grow again. The bunch shape changes as well from a more rectangular shape to a triangular like. In DAFNE a lattice with a negative α_c has been already tested and it has been observed a bunch length decrease up to a factor 2 as shown in fig. 2, leading to a potential correspondent gain in luminosity. Tests with colliding beams will be performed in the next few months.

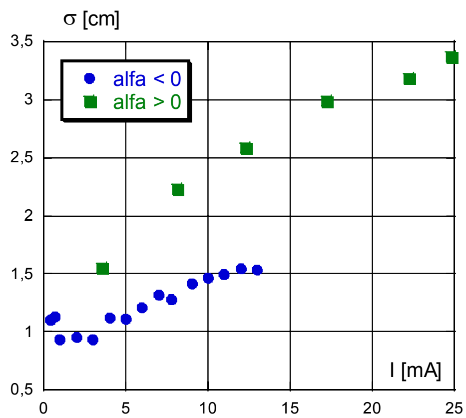


Fig.2: DAFNE bunch length vs current with positive and negative momentum compaction α_c for the electron ring

NEXT GENERATION FACTORIES

The next generation factories designs aim to a luminosity of the order of 10^{36} for the B factories and 10^{34} for the phi. These projects are targeted to begin operations around 2011 [3] [4] [5] .

Tab.3: Parameters set for super factories

	PEP-II	KEK	DAFNE	
LER energy	3.	3.5	0.51	GeV
HER energy	9.7	8.0	0.51	GeV
LER current	22.0	9.0	3.5	A
HER current	10.1	4.1	3.5	A
β_y^*	1.5	3.0	2.5	mm
β_x^*	15	20	30	cm
X emittance	79	18	260	nm-rad
Estimated σ_y^*	1.1	0.7	1.6	µm
Bunch spacing	0.5	0.6	0.5	m
Number of bunches	6900	5000	150	
Collision angle	30	30	30	mrads
Luminosity >	1.0×10^{36}	0.5×10^{36}	1.0^{34}	$cm^{-2}\ sec^{-1}$

Tab.3 shows a parameter list for such machines. Some of their most important characteristic are listed below.

Very short lifetimes (few minutes), so the injection has to be as continuos as possible.

Very small β_y^* (<2mm), this will require very strong IR quadrupoles, probably superconducting and possibly a dedicated chromaticity correction to preserve a good dynamic aperture.

Very small bunch lengths (<2mm) and high currents (>10Amps), demand very powerful RF systems, for example SUPER-KEKB plans for more than double the RF stations with respect to KEKB. Bellows, pumps and vacuum chamber are being redesigned, to reduce as much as possible higher order modes, resistive walls, electron clouds and to handle the higher synchrotron radiation flux.

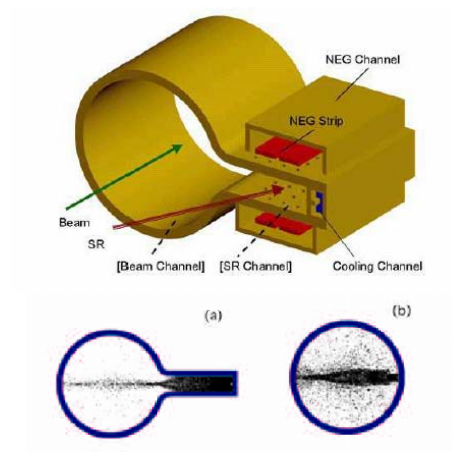


Fig. 3:Schematic view of a vacumm chamber with anti-chamber and simulation of the electron cloud with (a) and without (b) anti-chamber.

Higher RF frequency to increase the number of bunches is considered for all the upgrades.

Damping rates of the bunch by bunch feedbacks have to be decreased and their frequency response improved to meet the shorter bunch spacing. New designs are currently under study.

Crab cavities to reduce the luminosity loss due to the crossing angle will be necessary, a first cavity that will make the beam to crab all along the ring, will be soon installed at KEKB.

Arc lattices have designs very similar to the present ones and allow to reuse a lot of the existing magnets. Fig.4 shows the non-interleaved 2.5-pi cell adopted by SUPER-KEKB, that has a wide tunability of all the critical parameters, togheter with a large dynamic aperture, thanks to the paired sextupoles.

The phi factory design presents additional challenges, due to the lower operating energy; the damping time has to be reduced as much as possible and the tousheck lifetime has to be maximized

The lattice proposed for DAFNE [5] is shown in fig.5. It provides high radiation damping since the paired positive and negative bending. The dispersion is maximum for both the high β_x and β_y points, ensuring a good chromatic correction. A most important feature is that it naturally generates a very high negative momentum compation, such that the microwave instability threshold occurs at a much higher single bunch currents (>10mAmps). Moreover with a big RF voltage, the longitudinal tune can be made very high (120-150 degrees), in such condition the bunch length along the ring varies (fig.6) allowing very short bunches at the IP and much longer bunches in the more harmful locations, like RF cavities and kickers [6] .

Finally it has to be pointed out that all the new designs tend to maintain the same footprint of the current accelerators, mainly to reduce costs and time necessary for the installation, with the exception of a possible positron damping ring for SUPER-KEKB.

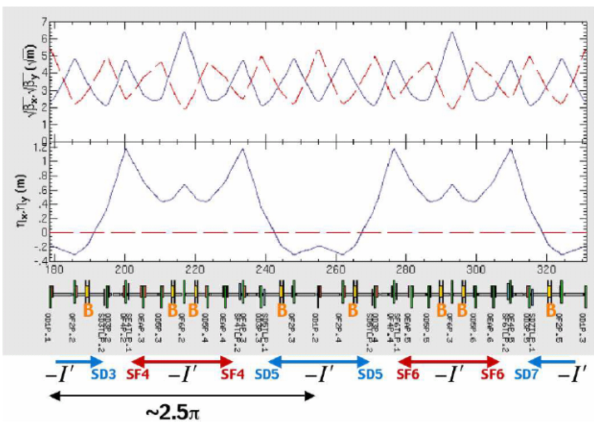


Fig. 4: Super-KEKB Arc Optic functions

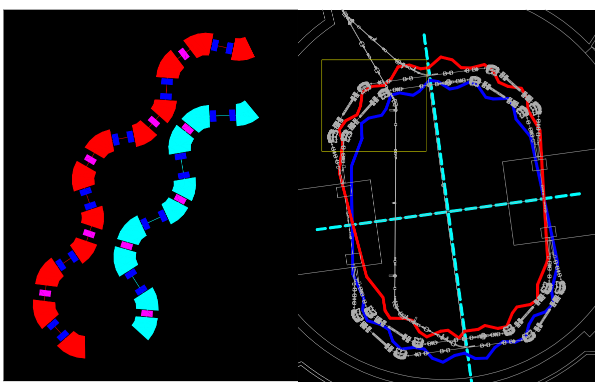


Fig. 5a: Particular of the Super-DAFNE Arc and Super-DAFNE layout

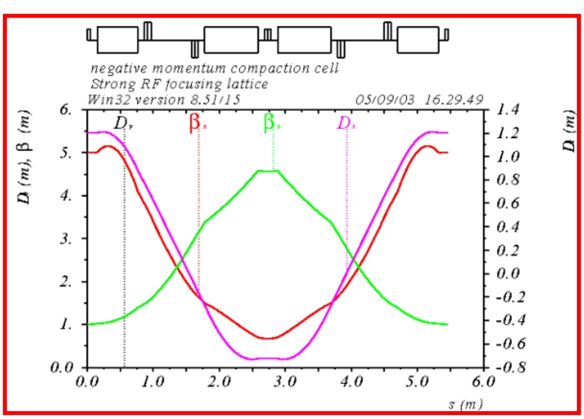


Fig. 5b: Super-DAFNE Arc Optic functions

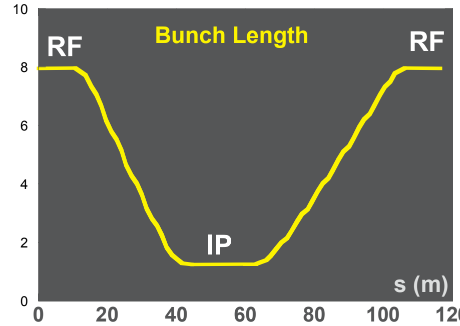


Fig.

Fig. 6: Bunch length along the Super-DAFNE ring for V_{rf}=10MV, α_c =-0.16, ν_{rf} = 503MHz

CONCLUSIONS

The factories have so far met and exceeded the design luminosity with exception of DAFNE that had an even more ambitious target, considering the lower energy and smaller ring.

Almost 5 years of experience proved that was much easier, although not without hard work, to bring the IP sizes way below the original design values than to bring the ring currents up to the specs. This last point has been very challenging and a lot of different problems have been met and solved to reach the present very high currents. Therefore this will be the most important key for the super-factories that require an increase of about a factor 5-10 in the operating currents, with a lot of foreseen and unknown problems to be faced.

The currently operating factories are still providing useful data for particle physics and are constantly stimulating the accelerators physicist to go further beyond in exploiting as much as possible the potential of the existing machines. The physics community is looking forward with great expectations for the next step, that should provide useful physics in the low and mid energy range for the next decade.

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