AN ASYMMETRIC LINAC-RING COLLIDER FOR BARYON TIMELIKE FORM FACTOR MEASUREMENTS WITH EXISTING HIGH ENERGY STORAGE RINGS

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Abstract

It is considered the possibility of using a positron storage ring like CESR and a low emittance, high duty cycle electron linac or a CW racetrack microtron of 100-200 MeV to realize an asymmetric collider providing a luminosity L~10^{30} cm^{-2}s^{-1}. A suitable linac can be based on the superconducting modules developed for the TESLA Test Facility (TTF) at DESY or for CEBAF at TJ Laboratory. The microtron option can be developed similarly to the existing first 2-stage of the Mainz microtron or based on the studies for the RTM of NIST/LANL in late 80's.

1 INTRODUCTION

The energy range of the existing e^+e^- storage rings no longer spans the $p\bar{p}$ and $n\bar{n}$ pair production threshold with adequate luminosity to improve the statistics and data quality of the old experiment. Quite unexpected results from the FENICE experiment [1], which measured the neutron e.m. form factor from the reaction $e^+e^- \to n\bar{n}$, are pushing for a new e^+e^- collider at c.m. energy around the baryon pair threshold. Besides the low cross sections, an additional difficulty in these measurements is due to the low kinetic energy of the emerging particles. In order to overcome the difficulty of detecting the low energy neutron coming from the $n\bar{n}$ pair nearly at rest in the laboratory frame, as in a symmetric storage ring, an asymmetric collider has been considered.

Such a a machine could be based on an existing high energy storage ring, e.g. CESR at energy ~5÷8 GeV, where an intense positron beam is stored, and a low energy electron beam at an energy ≤200 MeV. The range of electron energy E_e for head-on collision with a positron beam of energy E_p providing invariant mass √s is given by

$$s = 4E_p E_e . \qquad (1)$$

The center-of-mass energy range between the $n\bar{n}$ threshold and √s=3.1 GeV as a function of the electron energy E_e is shown in fig. 1 for two different values of E_p. The invariant masses corresponding to the baryon pair thresholds and the J/ψ mass are also shown.

Crucial parameters of the electron accelerator are the beam emittance, which must be comparable with that of the storage ring, and the average current which, although ~10^3 times lower than the stored current, is nevertheless very high when compared to typical linac currents. A linac in the injection chain around a storage ring cannot provide such a beam quality, but the required performances are achieved at some linac based FEL facilities. The bunch separation in the linac beam must be an integer multiple of that between the bunches stored in the ring and the rf systems must be phase-locked to ensure the stability of the collision point.

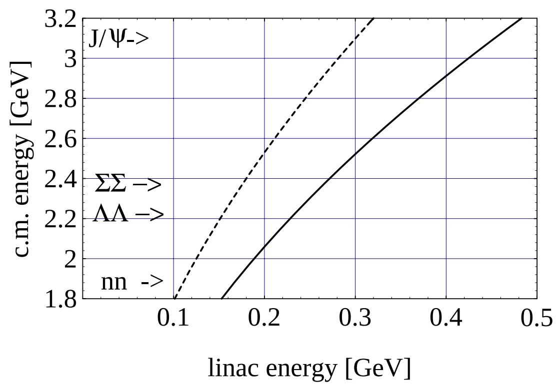

Figure: 1 Invariant mass vs. electron beam energy in head on collision with the stored positron beam of energy 5.3 GeV (continuos line) and 8 GeV (dashed line).

In order to improve the statistical accuracy with respect to FENICE by at least an order of magnitude in a reasonable running time a new collider must provide a luminosity L>10^{29} cm^{-2}s^{-1}. Comparing this value with the luminosity L~10^{33} cm^{-2}s^{-1} expected at CESR after planned upgrade to raise the storable current to 500 mA the goal should be attainable with I_{av}>50 µA. This current can be obtained either by a 5 mA, 1% duty cycle sc linac or by a CW machine.

Electron beam polarization would provide a valuable tool to help to disentangle the contribution to the neutron form factor due to the magnetic part G_M and the electric part G_E.

2 THE LUMINOSITY OF A LINAC-RING COLLIDER

The luminosity of an head-on linac-ring collider is given by

$$L = \frac{n_e n_p f_c}{4\pi\sigma_x\sigma_z} \qquad (2)$$

where n_e and n_p are respectively the electron and positron bunch population, f_c is the collision frequency, given by the stored bunch frequency f_b times the linac duty cycle δ. The beam sizes σ_x, σ_z are defined by the ring lattice and energy and it is assumed that the linac beam sizes can be matched to those of the ring. As far as the "geometrical" coefficients in the denominator of eq.(2) is concerning, it is best to run the ring at the lowest as possible energy E_p, because $\sigma \propto E_p$. However this implies higher sensitivity of the storage ring to beam-beam perturbation and higher electron beam power in the dump. Increasing the ring energy, and therefore decreasing the linac energy to satisfy eq.(1), has similar effect on the linac and ring beam sizes owing to opposite energy dependence

$$\sigma_{linac} = \sqrt{\beta_{x,z}\varepsilon_{linac}^{(n)} / E_e}\,,\ \sigma_{ring} = \sqrt{\beta_{x,z}\varepsilon_{x,z_{ring}}^{(n)} E_p^2}$$

where $\varepsilon_{linac}^{(n)}$ and $\varepsilon_{ring}^{(n)}$ are respectively the linac and ring normalized emittance. It is worthwhile noting that a reduction of E_e implies a reduction $\propto E_e^2$ of the rf power in the linac accelerating structures: by trading off between the peak power and the duty cycle it is possible in principle to compensate for the luminosity reduction at higher ring energy by increasing the linac duty cycle.

2.1 Machine parameters

A luminosity estimate has been carried out assuming the values experimentally achieved at CESR in the old operating mode [2] which stored 112 mA in 7 bunches. The parameter set is listed in table I.

Table I - Main parameter of the storage ring

Machine parameter	**value**	**unit**	**Note**
Energy E_p	5.3	GeV	
Hor. emittance $\varepsilon_{SR,x}$	1.2 10^{-8}	m rad	@ 1.0 GeV
Hor.-vert.coupling k	0.015		
Positron/bunch n_p	2.5 10^{11}		@ 112 mA
Bunch spacing s_b	300	ns	
Horiz. opt. funct. β_x^*	1.0	m	
Vert. opt. funct. β_z^*	18 10^{-3}	m	
Beam size σ_x	574	µm	
Beam size σ_z	10	µm	
Damping time t_x,t_z	26.9	ms	
Damping synchr. t_e	13.4	ms	

The parameters referring to the electron beam, listed in table II, are based on experimental data or design specifications at the TESLA Test Facility at DESY [3]. These values are comparable with the performances achievable by industrial grade sc technology (see for instance the CEBAF project for a FEL based industrial application of sc technology [4]), so they are a reliable basis for the estimate of the collider performances.

The specifications of the TESLA Test Facility linac are of course suited to linac-linac collider operation, therefore some features which could provide a boosting of performances as a linac-ring collider have not been considered; for instance the R&D privileges higher accelerating gradient to get a shorter linac instead of a longer macropulse.

The luminosity attainable with the parameters listed in table I and table II is 1.7 10^{29} $cm^{-2}s^{-1}$.

Table II - Main parameter of the linac

Machine parameter	**value**	**unit**	**Note**
Energy E_e	0.16	GeV	@ $n\bar{n}$ th.
Length L	45	m	
Emittance $\varepsilon_{linac}^{(n)}$	1.0 10^{-8}	m rad	@1 GeV
Horiz. opt. funct. b_x^*	5.0	m	@ $n\bar{n}$ th.
Vert. opt. funct. b_z^*	1.5 10^{-3}	m	@ $n\bar{n}$ th.
Macropulse current I_m	8	mA	
Particles/bunch n_e	1.8 10^{10}		
Bunch frequency f_b	3.333	MHz	
Pulse duration T_{on}	1.0	ms	
Repetition rate f_r	10	Hz	
Duty cycle δ	0.01		

2.2 Improvements and Limiting Factors

The macropulse linac current limit requires that $n_e f_b$=constant; however, a reduction of linac pulse frequency implies a corresponding increase of n_p so that at constant current both in the ring and linac beam $L \propto f_b^{-1}$. The corresponding luminosity as a function of the number of bunches stored in CESR is shown in fig. 2.

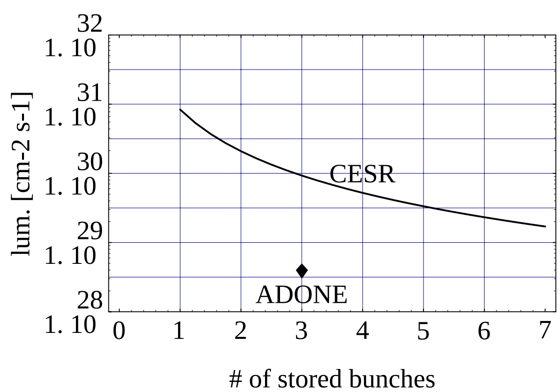

Fig. 2 - Luminosity vs. number of stored bunches in CESR at 112 mA (continuous line). The luminosity achieved at ADONE for the FENICE experiment is shown for comparison.

A limit to the bunch density of the colliding beams is given by the beam-beam perturbation characterized by the linear tune shift parameter ξ_i; the experimental data from all the existing storage rings indicate that a bunch density limit corresponding to ξ_{max}~0.05 cannot exceeded. In the case of a linac-ring collider this limit apply of course only to the stored positron beam. The maximum values of ξ for the cases in fig. 2 are ξ_x=0.032 and ξ_z=0.033. It is to note that this perturbation affects the stored beam with a low duty cycle, so that the damping can restore the initial beam condition before the next linac macropulse. The average effect on the beam should be not higher than that due to an equivalent ξ_{eq} given by the previous ξ weighted by the duty cycle plus the damping times: $\xi_{eq,i}=\xi_i\ f_r\ (T_{on}+\tau_i)$. The resulting values are well below the range $0.02<\xi_{meas}<0.04$ measured at CESR in a variety of conditions [5]. Probably the single bunch density will be limited by the longitudinal instability before the previous limit applies; it should depend strongly on the planned upgrade of the rf and feedback systems.

These considerations applies if I_{av} is provided by a pulsed beam with $\delta\leq 0.01$. Of course a trade off as large as possible between n_e and f_b is desirable since this relaxes the ring specifications and reduces the perturbation of the stored beam. Moreover, the increase of the current up to 500 mA is achievable mainly increasing the number of the stored bunches.

3 THE MICROTRON OPTION

The average current could be obtained by a low current CW machine like a small storage ring or a racetrack microtron. In this case the beam beam perturbation on the positron beam is reduced by a factor $1/\delta$ and a corresponding increase in luminosity, at constant ξ, could be obtained by squeezing the beam size by the same factor at the interaction point. However, in the case of a low energy storage ring the perturbation affecting the stored beam is likely to be intolerable; although this option deserves a better insight, it is presently rejected because the short lifetime of the perturbed beam is expected be an intense source of background.

The CW racetrack microtron option has no such a limitation since it provide a disposable beam. Moreover the footprint of the microtron is small and can be easily allocated at some distance from the ring. The transport line can be optimized for the best collision point layout without ring lattice constraints. If the perturbation on the stored positron beam could be made negligible, parasitic operation becomes possible as an alternative to dedicated operation largely increasing the running time of the experiment.

The existing machines providing I_{av} ~ 100 µA use normal conducting accelerating modules, which make them simpler and cheaper with respect to a superconducting based accelerator. The suppression of higher order modes excited by recirculating beams was considered the major drawback of the sc structures at the time of their construction; in the meanwhile wide experience has been gained in this field so the feasibility of a superconducting CW microtron deserves a better consideration now. Recent operation of the TTF 10 MeV capture section at 8 mA indicates that a 200 MeV, 20 passes machine providing 400 µA is conceivable.

The performances of the operating Mainz RTM [6] and of the IASA machine [7], derived from the discontinued NIST/LANL FEL program, are listed in table III for comparison.

Table III - Parameter list of existing or planned RT microtrons providing Iav > 100 µA

RTM machine	Mainz	IASA	unit
Energy max	185	247	MeV
Average current	107	100	µA
Injection energy	14	42	MeV
Gain per turn	3.2	8.5	MeV
# of recirculations	51	25	
Energy width	36	--	keV
Emittance	$14\ 10^{-9}$	--	π m rad
Magnet spacing	~ 6	8.6	m

4 CONCLUSION

The construction of a dedicate electron accelerator for one specialized and time limited experiment could seem expensive. However the electron beam quality is very high and it can be easily exploited for up-to-date experiments in different fields, such as FEL or γ production for solid state or nuclear physics, by Compton or Thomsom scattering, thereby largely improving the cost/productivity ratio.

The performances achieved in the past by CESR and those expected by a TTF-like linac allow to design a linac-ring collider providing a luminosity more than an order of magnitude better than the luminosity for the FENICE experiment with boosting in the laboratory frame further improving the effectiveness of the experiment. Potential upgrading of both the linac and the storage ring performances should provide safe margins to easily reach the goal of luminosity $L = 10^{30}\ cm^{-2}s^{-1}$.

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