STATUS REPORT ON ACO

The Orsay Storage Ring Group[†)]

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(presented by D. Potaux)

Abstract

Development and beam studies on ACO are presented concerning : experiments with a longitudinal solenoid field in the interaction region, new magnetic structures and beam polarization.

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During the last two years ACO was used for high energy physics experiments with large solid angle detectors. In the experiment performed in 1970, the neutral modes of the ϕ and ω^o were measured. New results were obtained on $\omega \to \pi^+\pi^-\pi^o$ and $\rho \to \pi^+\pi^-$, and also on ω-ρ interference. In 1971, another experiment, which has just been completed, measured the $\mu^+\mu^-$ yield around the ϕ^o energy.

At 510 MeV the maximum luminosity[*] is now 2.2×10^{32} cm^{-2} h^{-1}. The improvement by a factor 2 obtained in 1971 is due to a better routine, and very likely to a better stabilization of the power supplies.

During the same period, beam studies were made concerning :

- the influence of a solenoidal field on the performances of the machine,
- preliminary tests with new periodic structures,
- measurements on beam polarization.

1. ACO with a solenoidal field

New detectors in preparation for ACO require the use of large solenoidal fields in order to measure precisely the momenta of outgoing particles. In view of this, a model of the solenoid was installed during the last two months of 1970 in the experimental section of ACO, in order to study the influence of a longitudinal magnetic field on beam behaviour, more specially on beam-beam limit and luminosity.

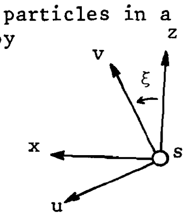
The solenoid we used consists of three independant coils. Its total length is 1.30 m, the magnetic length of the central coil about 55 cm and the maximum field about 1.6 T.

We decided to keep the usual operating point $\nu_x = 2.845$, $\nu_z = 0.845$, therefore to compensate both the focussing and the coupling effects of such a field. The coupling introduces a split of the wave numbers which can be compensated by using, either the side coils so as to cancel the integrated longitudinal field, or two skew quadrupoles located in the opposite straight section. In both cases, the focussing effect is compensated with the quadrupoles of the ring.

*) the mean luminosity over the last experiment being 9×10^{31} cm^{-2} h^{-1}.

1.1 Compensation by "antisolenoids"[1,2)]

We can study the motion of the particles in a rotating coordinate system defined by



$$x = u \cos \xi + v \sin \xi$$

$$z = -u \sin \xi + v \cos \xi$$

where $\frac{d\xi}{ds} = - \frac{e}{2p} B(s)$.

If $\int B(s)\, ds = 0$, there is no coupling between the motion in u and v directions, and the compensated solenoid is equivalent to a focussing lens with the gradient

$$K(s) = \left[\frac{e}{2p} B(s)\right]^2$$

In our case the so-defined lens has a magnetic length equal to 85 cm. The gradients of the quadrupoles can be computed as functions of the solenoidal field, so that the wave numbers stay constant. ACO with a solenoid is a one period structure, and the theoretical beam-beam limit corresponds to the crossing in the RF straight section. In this crossing point, the linear tune shift $\Delta\nu$ is supposed to be a constant, for instance .025.

The experimental results for the operating point and the beam dimensions (fig. 1) are in good agreement with the theoretical predictions, but the beam-beam limit was found lower than expected (fig. 1) and thus the luminosity (fig. 3).

1.2 Compensation by skew quadrupoles[2,3)]

The coupling effect of longitudinal fields and skew quadrupole fields, characterized respectively by coupling coefficients Q_s and Q_q, mainly results in a wave number splitting :

$$\nu_1 - \nu_2 = 2 \sqrt{(Q_s + Q_q)\,(Q_s + Q_q^*)}$$

Thus the wave number splitting due to solenoidal fields can be cancelled by appropriate skew quadrupoles. For instance we get for a solenoid set in a straight section :

$$Q_s = - \frac{1}{8\pi} \frac{\beta_z + \beta_x}{\sqrt{\beta_x \beta_z}} \frac{e\,c}{E} \int B(s)\, ds$$

where β_x and β_z are the values of the β functions at the center of the section.

For two 45° twisted quadrupoles of convergences Γ and $-\Gamma$, symmetrically set in the opposite straight section at a distance ℓ from the middle, we get :

$$Q_q = \frac{\Gamma\ell}{2\pi} \frac{\beta_z - \beta_x}{\sqrt{\beta_x \beta_z}}$$

Cancellation of $\nu_1 - \nu_2$ is obtained for :

$$\Gamma = \frac{1}{4} \frac{\beta_z + \beta_x}{\beta_z - \beta_x} \frac{e\ c}{E} \frac{1}{\ell} \int B(s)\ ds$$

Experimental results are in good agreement with this linear approximation. Unfortunately the beam-beam limit and the luminosity (fig. 4) were found to decrease more rapidly than with the antisolenoids.

1.3 Conclusions

- The comparison between the two methods led us to choose the compensation by antisolenoids.

- In this case, with a solenoidal field of 1 T over a magnetic length of 55 cm, we only loose at 510 MeV 25 % on the luminosity.

- The influence of a compensated solenoid is well understood, except for the beam-beam effect. But probably beam-beam effect is not understood even without a solenoid.

2. ACO NEW PERIODIC STRUCTURES : ACO 1[4] AND ACO 2[5]

We have recently started a systematic study of beam-beam effect with two new structures allowing to change the β functions, while keeping the wave numbers constant. If the maximum $\Delta\nu$ is really a constant, the luminosity could be increased by an order of magnitude. The main features of the two structures are summarized in table 1.

With the 2 periods structure we have made a set of experiments at 380 MeV with low β's. The experimental values for β functions and beam transverse cross section agree with computation. At the operating point we chose, the expected improvement as compared to the usual 4 period structure was a factor of 7.4 in luminosity, resulting from an increase of 3.6 for the beam current. Actually, the limit current was found to be roughly the same and the luminosity dropped by a factor of 2. The corresponding $\Delta\nu = Nr_e\beta/\gamma S$ is .008 per crossing instead of .03 for the 4 period structure at the same energy.

The limit current with crossing in large β regions was found to be the same. In conclusion one should put a question mark on the .025 limit or look for other limiting effects.

Remark on beam-beam limit

Up to now, the beam-beam limit on ACO was assumed to be incoherent. We recently detected a coherent frequency approaching the revolution frequency when we go near the limit. The corresponding $\cos 2\pi\nu$ seems to be a linear function of the stored current. This point deserves further investigation.

3. BEAM POLARIZATION

The gradual building-up of the polarization of an electron or a positron beam rotating in an homogeneous magnetic field, which was predicted by Sokolov and Ternov[6] has been looked for in ACO. We have measured the variation with time of the Coulomb scattering cross-section within a single bunch of positrons, using the experimental arrangement sketched on fig. 6. A pair of particles which have exchanged in average 7 % of their energy in the quadrupole sections are separated by the following magnet and detected by counters 1 and 2 for the particle going outward and by counter 3 for the particle going inward. A fourfold coincidence is made also with the bunch passing signal. The overall geometry of the system was much better defined than the one used in previous tests. In order to maximize the effect, the distance of the counters to the beam was chosen as large as possible compatible with a suitable counting rate.

The counting rate $\dot{n}$ is proportional to the square of the current, to the inverse of the volume of the bunch ($V = \Delta X \times \Delta Z \times \Delta\ell$) and to the cross section for Coulomb scattering within the bunch, integrated over the acceptance of the system :

$$\dot{n} = k \frac{I^2}{\Delta X \times \Delta Z \times \Delta\ell} \times \sigma$$

If polarization occurs the normalized counting rate Y

$$Y = \dot{n} \frac{\Delta X\ \Delta Z\ \Delta\ell}{I^2}$$

should exhibit a typical variation with time of the form :

$$Y = a - b \left(1 - e^{-t/\tau}\right)^2 .$$

The operating point E = 536 MeV, $\nu_x = 2.845$, $\nu_z = 0.88$ was selected to be as far as possible from depolarizing resonances[7]. Accurate measurements of the current and of the beam transverse dimensions were made every 15 minutes during each experiment which lasted in average 10 hours. Using measurements on bunch lengthening, small corrections were applied to account for the variation of $\Delta\ell$ with current.

Fig. 6 shows the combined results of 5 different runs fitted with three free parameters : the experimental building-up time τ, the initial and asymptotic normalized counting rates.

In the following table, we compare the theoretical and experimental values :

	τ	$(Y_M - Y_m)/Y_m$
Theoretical values	163 minutes	22 %
Experimental values	167 ± 37 minutes	19 ± 2.2 %

The absolute counting rate agrees with the expected value.

Two other tests were made :

i) At 440 MeV ($\frac{g-2}{2}\gamma = 1$), a similar experiment shows no sign of decrease for σ, in agreement with the fact that the beam depolarizes very fastly.

ii) After letting the beam polarize at 536 MeV for 10 hours, the energy was then cycled to 440 MeV (2 minutes) and the initial conditions at 536 MeV were then reproduced. A noticeable step for the normalized counting rate is observed in agreement with the fact that polarization has disappeared.

In conclusion, we can say that, at least with a single positron beam, polarization has been observed, compatible with the maximum value and the time constant predicted by Sokolov and Ternov and beam depolarization occurs very fastly when going to 440 MeV.

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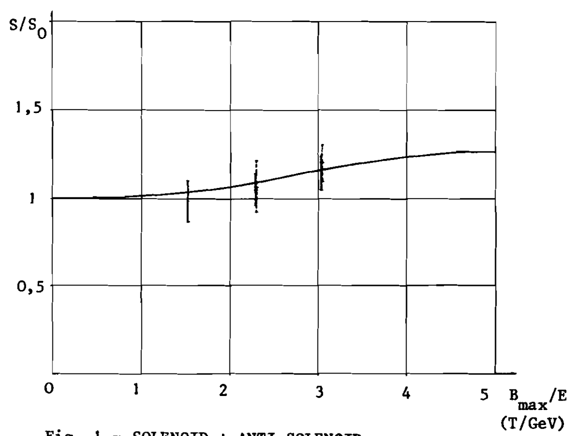

Fig. 1 - SOLENOID + ANTI-SOLENOID : Beam cross-section

E = 510 MeV

I values deduced from $I^+I^-/\dot{n}$

I values deduced from beam-size measurements

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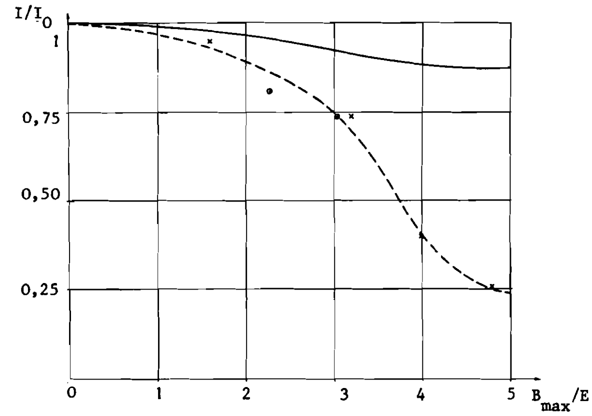


Fig. 2 : SOLENOID + ANTI-SOLENOID : Beam-beam limit

— theoretical curve ($\Delta\nu$ = constant)

× measurement at 243 MeV

• measurement at 510 MeV

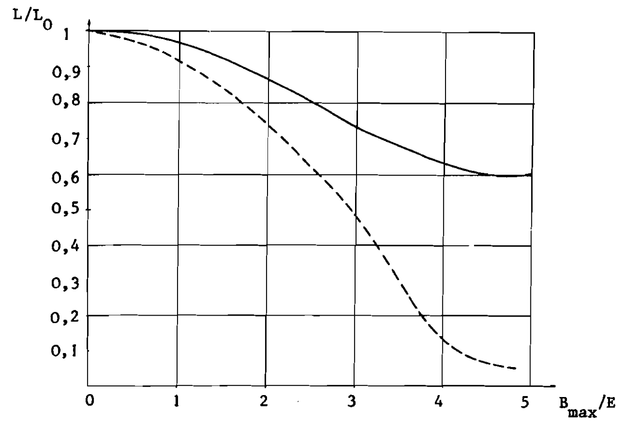


Fig. 3 - SOLENOID + ANTISOLENOID : Luminosity versus solenoidal field

___ Theoretical limit

\- - Experimental limit

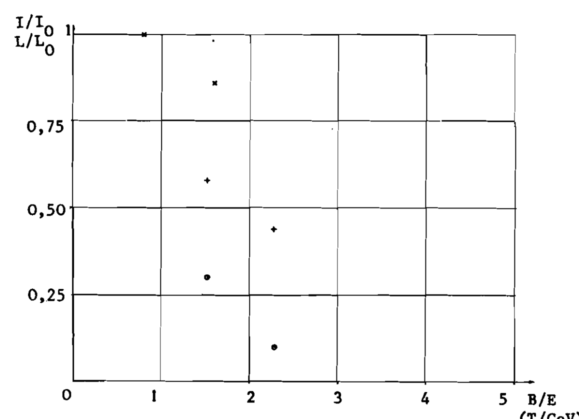
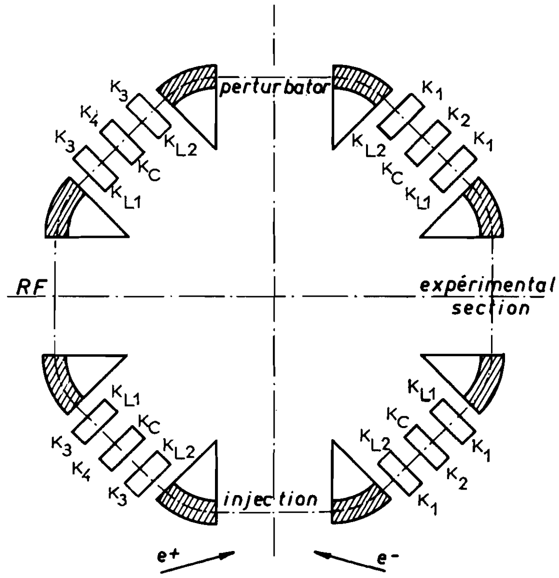


Fig. 4 - SOLENOID + SKEW QUADRUPOLES : Beam-beam limit and luminosity

× Beam-beam limit at 243 MeV

\+ Beam-beam limit at 510 MeV

• Luminosity at 510 MeV



ACO NEW PERIODIC STRUCTURES

fig. 5

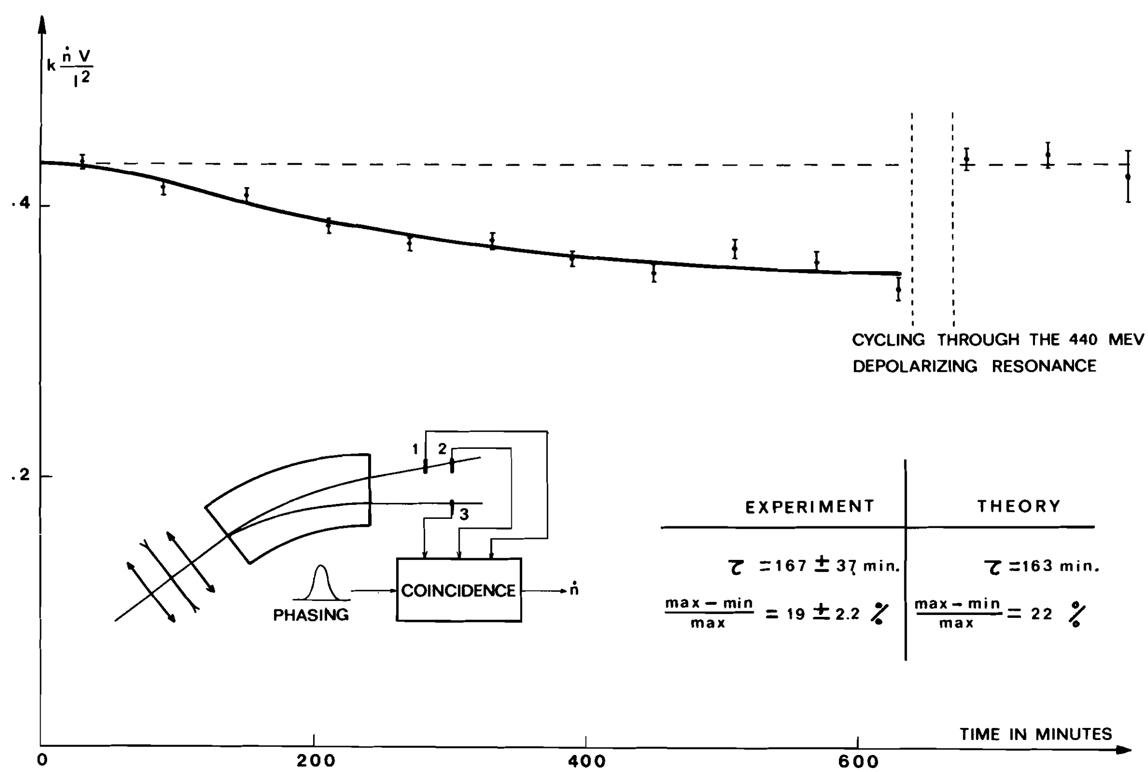
TABLE I

ACO 1

K_1	K_2	K_3	K_4	β_x	β_z	I/I_0	L/L_0
6,5688	- 7,7159	6,5688	- 7,7159	1,78	4,01	1	1
6,8760	- 8,1902	6,2622	- 7,2114	1,00	1,04	1,1	2,9
7,1500	- 8,4688	5,7215	- 6,4283	0,39	0,37	1,7	12
7,3270	- 8,6326	4,6864	- 4,8261	0,16	0,14	2,7	48

ACO 2

K_C	K_{L1}	K_{L2}	β_x	β_z	I/I_0	L/L_0
- 7,7159	6,5688	6,5688	1,78	4,01	1	1
- 7,50	7,4038	5,4523	0,61	2,06	3,6	7,4
- 7,30	8,4200	4,5965	0,48	1,40	13	34



POLARIZATION OF A POSITRON BEAM

FIG. 6

DISCUSSION

C. PELLEGRINI : Did you also measure the electron or positron polarization with two beams in the ring ?

P. MARIN : Not yet. We intend first to measure the polarization, if any, in the usual conditions with a round beam on the coupling resonances. We will then proceed to measure it with two beams in the usual operating conditions.

C. PELLEGRINI : You said that with the low-beta structure the limiting current remains the same and the luminosity decreases by a factor two. Did you really measure the decrease in luminosity ?

P. MARIN : We had no monitoring measurements. The results given here are deduced from intensity and dimension measurements. Measured dimensions are in agreement with theoretical predictions.

C. PELLEGRINI : Can the observation of a coherent transverse signal near the limit luminosity be taken as an indication that this effect, and not the incoherent beam-beam interaction, limits the luminosity

P. MARIN : This point seems very interesting, but we had not enough time to make systematic studies.

P. MORTON : Were the two beams that collided in the low-beta experiment of equal intensity and did you have an electric quadrupole on to separate the tunes ?

D. POTAUX : The two beams were of equal intensity. We had no separation of the wave numbers.

F. AMMAN : Coming back to the polarization, do you have any indication of polarization in high energy physics experiments ?

P. MARIN : The high energy physics experiments which have been carried out on ACO until now have not shown any sign of polarization effects. However, the expected effects in the usual conditions during these experiments are not large and the statistics of the events are not good enough to really decide.

A. SKRINSKY : Have you tried, during the polarization experiment, cycling not through 440 MeV energy, but through higher energy (say, 450 MeV) ?

P. MARIN : In the experiment which is reported here we only went to 440 MeV. If I put your question in another way, can we try to measure the width of the depolarising resonances ? This is probably difficult with ACO since the polarization building-up time is long and requires about 10 hours to reach almost full polarization and many runs would then be needed. It is probably easier in this respect to do it on VEPP-2.