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REVIEW OF MINI BETA LUMINOSITIES IN PETRA AT DIFFERENT ENERGIES

by

A. Piwinski

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1. Introduction

The mini beta operation with PETRA[1,2] started in March 1981. Since that time many data were taken at 17, 11 and 7 GeV. The maximum luminosities, tune shifts, limitations etc. are summarized and compared in this note.

In the mini beta insertion the free space for each of the 4 detectors was reduced from 2x7.5 m to 2x4.5 m. Hence 2 detectors with solenoid fields, Jade and Tasso, must run without compensation. Their field polarity is now chosen such that they compensate each other partly. The remaining coupling produced by these 2 solenoids does not play any role at higher energies, but it can make the operation at 7 GeV somewhat more difficult[3].

The betas at the 4 interaction points could be reduced to β_{xo} = 120 cm and β_{zo} = 8 - 9 cm. A vertical beta of 6 cm or less is possible but leads, with the present 2 sextupole families, to a limitation of the energy acceptance; i.e. the compensation of the larger chromaticity with stronger sextupole strengths limits the amplitude of synchrotron oscillations[4]. There is hope that in future operation with 4 or 6 sextupole families this difficulty can be overcome.

Computer simulations[5] and measurements[6,7] in the last year have shown that operation with low Q (Q_z = 23.1) gives a smaller blow-up of the colliding beams than high Q (Q_z = 23.3). Therefore the storage ring was operated with low Q in the space charge limited energy region, i.e. at 7 and 11 GeV.

To reduce the energy consumption, only 1 out of 4 transmitters was used at 7 and 11 GeV, and 45 of the 60 five-cell cavities were short-circuited in order to avoid instabilities.

The luminosity at 17 GeV was nearly three times higher than last year. The reduction of both betas at the interaction points is about a factor of two, which gives an increase of luminosity by a factor of two. Hence there was an additional increase of luminosity due to an improvement of the operating conditions and due to a better symmetry of the ring. A new alignment of the quadrupoles gave a better symmetry of the optics which reduced the blow-up. Thus the maximum tune shift, which does not depend on the mini beta since the ratio of the vertical to the horizontal beta at the interaction points was not changed, was also larger than last year[8].

2. 17 GeV

The beams were injected at 7 GeV into a MI100-optics (β_{zo} = 100 cm) in which satellite resonances are considerably weaker than in a luminosity optics. During injection the rf frequency was increased by 5 to 6 kHz. This changes the damping partition and increases the natural bunch length by a factor of 1.5 to 2 which gives a higher limit for the vertical instability$^{9)}$. Maximum currents of 2x8 mA positrons and 2x8 mA electrons could be injected with 60 cavities. A transverse feedback was used in most cases but was not always necessary.

During the energy ramping the betatron frequencies were controlled automatically and the synchrotron frequency was kept constant by the operator. The tunes were $Q_x = 25.19$, $Q_z = 23.29$ and $Q_s = .07$. The machine was first ramped to a MI15-optics (β_{zo} = 15 cm) at 17 GeV. This intermediate optics is necessary since a linear change of all magnet currents from the injection optics to the luminosity optics leads to very large betas and large chromaticities on the way$^{10)}$.

The collision of the beams was made at the central rf frequency in the optcis MI9 with β_{xo} = 120 cm and β_{zo} = 9 cm. The calculated horizontal emittance was $\varepsilon_x = 2\text{x}10^{-7}$ radm. The maximum luminosity was $1.7\text{x}10^{31}\text{cm}^{-2}\text{sec}^{-1}$ obtained with 4x5.2 mA.

The maximum vertical tune shift or, more exactly, the maximum vertical space charge parameter ξ_z, derived from the luminosity, was .040. The maximum horizontal space charge parameter was $\xi_x = .016$, and the ratio of the emittances was $\kappa = \varepsilon_z/\varepsilon_x = 1.3$ %.

The maximum luminosity was not limited by the beam-beam interaction but by the maximum currents which could be accelerated to 17 GeV and by the background for the experiments. For bunch currents between 5 and 6 mA, satellite resonances began to cause beam losses during energy ramping. The background conditions often did not allow more than 4x5 mA.Although the vertical tune shift was very large there was only a small increase of beam height of 12 % due to the beam-beam interaction which can also be seen in fig. 2.

The maximum luminosity depended on the betatron and synchrotron frequencies which must not be to close to a resonance. Also a careful orbit correction

was important. Large luminosities were obtained only with rms-values of the orbit deviations of 1 mm or less. Spurious vertical dispersions were compensated with special orbit bumps in order to minimize the beam height. The background for the experiments could often be kept sufficiently small by small variations of the beam position in the interaction region. The life time of the beams was between 6 and 9 hrs.

The maximum number of inverse nanobarn per day and per experiment was 870. This corresponds to an average luminosity of $1.0\text{x}10^{31}\text{cm}^{-2}\text{sec}^{-1}$.

3. 11 GeV

The injection was done in a MI8-optics at "low Q" without changing the rf frequency. A MI100-optics was not suitable since the large variations of betas and chromaticities during the linear ramping cause current losses if the tune is close to an integer. On the other hand the small number of 15 cavities allowed the injection of maximum currents of 4x8 mA in the MI8-optics. The tunes were $Q_x = 25.19$, $Q_z = 23.12$ and $Q_s = .054$. A transverse feedback was used in most cases.

The luminosity optics was the MI9E with β_{xo} = 133 cm and β_{zo} = 9 cm. This optics has a larger horizontal emittance than the MI9. The calculation gives $.92\text{x}10^{-7}$ radm at 11 GeV and the central rf frequency. For a change of -1 kHz of the rf frequency it is $1.5\text{x}10^{-7}$ radm.

The maximum luminosity was $6\text{x}10^{30}\text{cm}^{-2}\text{sec}^{-1}$ at the central rf frequency, obtained with 4x4.5 mA, and $8\text{x}10^{30}\text{cm}^{-2}\text{sec}^{-1}$ with 4x5.7 mA at the reduced rf frequency.

The ratio of the emittances derived from maximum luminosity was κ = 14 % for both frequencies. The maximum space charge parameters were $\xi_x \pm .034$ and $\xi_z = .024$ at both rf frequencies.

The luminosity was sharply limited by the beam-beam interaction. When the bunch currents were only 0.2 mA above the limit the life time dropped from 9 hrs to less than a minute and one or both beams were lost. But also at good life time and far below the limit there was a considerable increase of beam height which can be seen from the specific luminosity in fig. 2.

The maximum luminosity depended sensitively on the betatron and synchrotron frequencies which had to be exactly between resonances. Also orbit distortions had a strong influence on the beam-beam interaction and the luminosity. Good luminosities were obtained only with rms-values of the orbit deviations which were smaller than .7 mm. The 4 bunch currents had to be equal. Differences of a few percent gave a larger blow-up.

The background for the experiments consisted of high energy particles and increased drastically near the limit of the beam-beam interaction. When the life time decreased, the background increased at the same time.

The maximum number of inverse nanobarn per day and per experiment was 360 which corresponds to an average luminosity of $4.1 \times 10^{30} cm^{-2} sec^{-1}$.

4. 7 GeV

The injection and the behaviour of the colliding beams were very similar to those described for 11 GeV. The injection optics was the same, and only the synchrotron frequency was smaller to avoid coherent synchrotron oscillations in the luminosity optics. The frequencies were $Q_x = 25.20$, $Q_z = 23.13$ and $Q_s = .042$.

The luminosity optics was the MI8E with $\beta_{xo} = 132$ cm and $\beta_{zo} = 8$ cm. Injection into this optics was not possible since the horizontal betatron phase advance between injection kickers was unfavourable. Therefore the optics had to be changed for each injection, but this could be done without the "massage" of all magnets that was necessary in the runs at higher energies.

The MI8E-optics has a larger emittance than the MI9E. Its calculated value is $.61 \times 10^{-7}$ radm at 7 GeV for the central rf frequency. The rf frequency was not constant during the runs but was increased in small steps in order to decrease the cross section of the beams and optimize the luminosity. Thus with decreasing currents one could always stay just below the beam-beam limit. The small change of the center-of-mass energy (≈ 7 MeV) did not play a role. At the beginning of a run the rf frequency was decreased by 1.2 kHz and the horizontal emittance was 1.13×10^{-7} radm.

The maximum luminosity was $1.9 \times 10^{30} cm^{-2} sec^{-1}$ with 4 x 3 mA. This gives a ratio of emittances of $\kappa = 38$ %. The horizontal and vertical space charge parameters were $\xi_x = .036$ and $\xi_z = .014$.

The luminosity was sharply limited by the beam-beam interaction as at 11 GeV. The betatron and synchrotron frequencies and the differences of the bunch currents had the same influence. Orbit distortions were not quite as critical as at 11 GeV; rms-values of 1 mm were sufficient for the maximum luminosity. It seemed that other asymmetrics dominated the small asymmetries produced by the orbit distortions. Those asymmetries can be caused by the solenoid fields of the detectors. The influence of the solenoids is proportional to $1/E^2$. For example, the compensation coils of the Cello magnet produce an asymmetric betatron phase advance of $2\pi \times .015$ which, as simulations have shown, should lead to a stronger blow-up. In a short experiment at the end of the runs it could be shown that without the field of the Cello magnet the same luminosity was obtained with only 4x2.4 mA, which gives a vertical space charge parameter $\xi_z = .02$.

Near the limit of the beam-beam interaction the background for the experiments was more sensitive at 7 GeV than at 11 GeV. Below the limit the life times of the beams were 13 hrs.

The maximum number of inverse nanobarn per day and per experiment was 120, corresponding to an average luminosity of $1.4 \times 10^{30} cm^{-2} sec^{-1}$.

5. Comparison

One of the most interesting questions is the energy dependence of the luminosity. Here the luminosities at only 2 of the 3 energies were limited by the same effect, the beam-beam interaction. Thus only these two luminosities can be described by the same power law which is found to be $L \sim E^{3.2}$.

For the interpretation of this dependence one has to take into account that the cross section of the beams neither had the natural energy dependence ($\sim E^2$) which is usually assumed, nor was it constant to fill the whole acceptance. The horizontal emittance was proportional to $E^{0.6}$, and the cross section, including the blow-up at maximum luminosity, was proportional to $E^{-0.4}$. Thus the energy dependence of the luminosity is partly determined by the controlled variation of the horizontal emittance and partly by the uncontrolled variation of the blow-up due to the beam-beam interaction.

The role of the initial vertical emittance is unknown since it is impossible to vary the vertical emittance without introducing vertical dispersions at the interaction points and asymmetric betatron phase advances between the interaction points. Both, dispersions and asymmetries, cause a stronger blow-up and destroy the influence of the initial vertical emittance.

The maximum vertical space charge parameter ξ_z also shows an energy dependence ($\sim E^{1.2}$). This behaviour is in agreement with the computer simulations. An exact comparison is difficult since the influence of the energy depends on the distortions of the machine and these distortions cannot be measured. However, the strength of the dependence indicates that the machine distortions were stronger at 7 GeV than at 11 GeV. Such distortions can be caused by the solenoids and are proportional to $1/E^2$.

The luminosity at 17 GeV is limited by the maximum currents and by the background for the experiments. An extrapolation of the values obtained at 7 and 11 GeV gives $L = 3.2\times10^{31}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ with currents of 4x9.3 mA. These currents cannot yet be accelerated to 17 GeV, but an increase to 7 or 8 mA per bunch seems possible. Thus an increase of the luminosity seems possible if at the same time the background can be improved.

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Energy/GeV	7	11	17
optics	MI8E	MI9E	MI9
β_{xo}/cm	132	133	120
β_{zo}/cm	8	9	9
horiz. emittance $\epsilon_x/10^{-7}$radm	.61	.92	2.0
change of rf frequency/kHz	-1.2	-1	0
horiz. emittance for changed rf frequency/10^{-7}radm	1.13	1.5	-
ratio of vert. and horiz. emittance at maximum luminosity/%	38	14	1.3
Q_x	25.20	25.19	25.19
Q_z	23.13	23.12	23.29
Q_s	.042	.054	.070
maximum luminosity/10^{30}cm^{-2}sec^{-1}	1.9	8	17
bunch current at maximum luminosity/mA	3	5.7	5.2
maximum ξ_x	.036	.034	.016
maximum ξ_z	.014	.024	.040
beam life time below the beam-beam limit/hrs	13	9	6-9
maximum number of inverse nanobarn per day and per experiment	120	360	870

Table 1

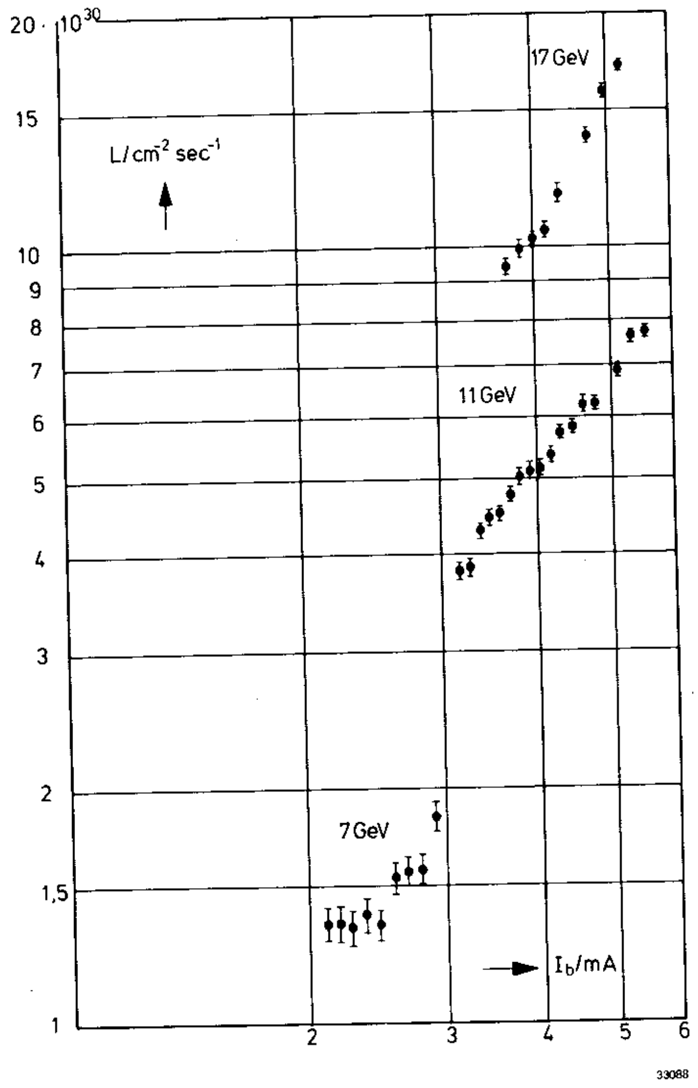

Fig. 1: Luminosity as a function of bunch current. For 17 and 11 GeV the values are averaged over 15 minutes, for 7 GeV over 30 minutes.

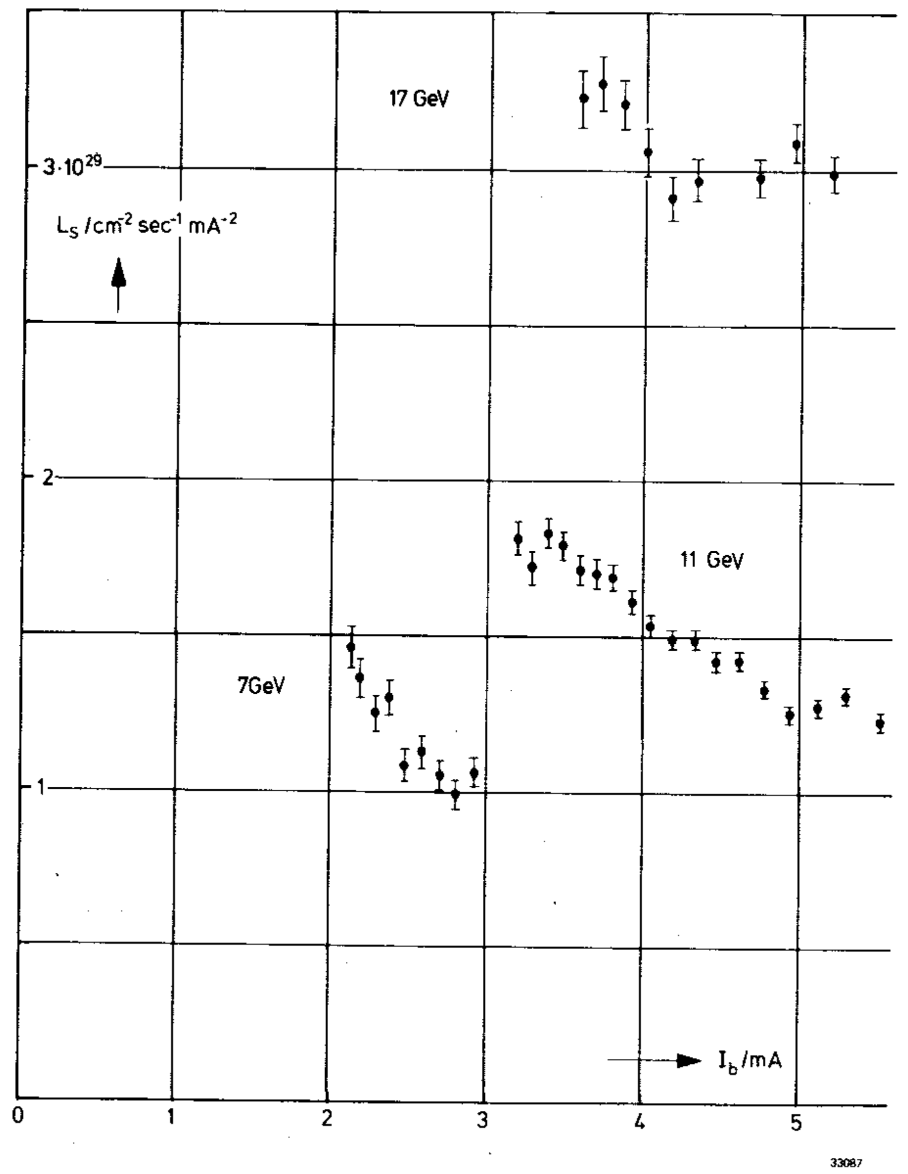

Fig. 2: Specific luminosity as a function of bunch current. The values are derived from fig. 1 ($L_s = L/(2I_b^+I_b^-)$).

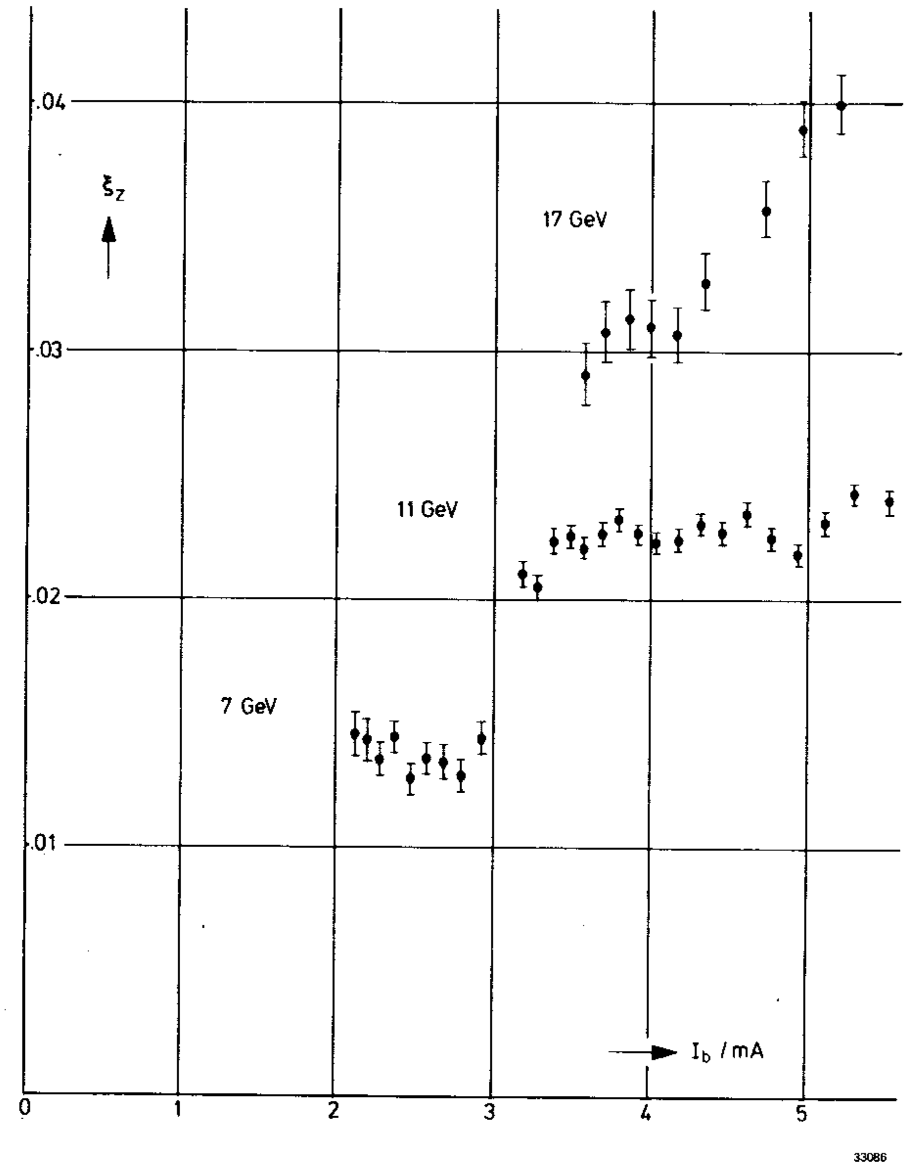

Fig. 3: Vertical space charge parameter ξ_z as a function of bunch current.