THE COOLER-SYNCHROTRON COSY *)

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The combined synchrotron-cooler-ring COSY+) is proposed to provide the Nuclear Physics Institute (Institut für Kernphysik) of the KFA Jülich and the cooperating universities++) with an advanced research tool. An energy range of about 20 MeV to about 1.5 GeV is envisaged. The existing cyclotron JULIC will serve as an injector for a variety of ions. Alternatively injection into COSY from a high-current linear accelerator would create a attractive situation.

A close cooperation of KFA and university groups in particular in Northrhine-Westfalia is envisaged for construction as well as for use of the facility.

COSY is basically a hexagonal synchrotron ring consisting of six identical separated function unit cells (see fig. 1). For acceleration in the fundamental harmonic a RF-system will be installed with a frequency range 0.5 MHz to 2.0 MHz. This allows acceleration from an energy of 40 MeV protons up to the bending limit. The ring has the two functions of a storage ring and an accelerator. Two long straight sections with telescopic beams are provided, one to accommodate an electron cooler the other one for beam manipulations (e.g. dispersion matching) at the main experimental target area where the best focus is located for the BIG KARL spectrometer. A 7 m bending radius was chosen. In a first stage (Stage I) operation up to 500 MeV protons is achieved at a magnetic field of 0.5 T. This is most suitable for nuclear structure studies in the so called "energy window". In a second step the magnetic field is increased to 1.1 T (Stage II) corresponding to an energy of 1.5 GeV for protons (2.25 GeV/c). This energy is well above several interesting thresholds for meson production and yields high momentum transfers in scattering experiments. A particular property of COSY is the possibility to reduce the phase space of intense beams by an electron cooler, initially with similar specifications to the one now under test at the LEAR ring at CERN. As experience develops, a more powerful cooler could be installed later on, allowing the cooling of

*) This article contains a short summary of a proposal available from Institut für Kernphysik der KFA Jülich. Details and references are given in the proposal.

+) COSY = Cooler Synchrotron

++) In particular the Universities in Northrhine-Westphalia with Nuclear Physics groups (Bochum, Bonn, Köln, Münster)

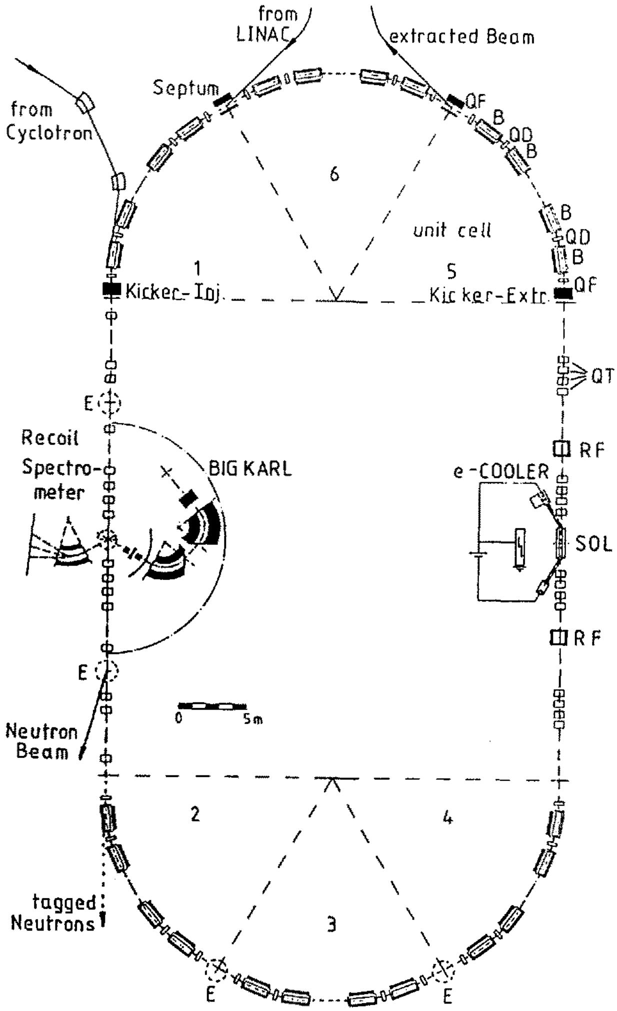

Figure 1:
Schematic view of the COSY with the essential elements of the ion optical system

QF,QD	=	Horizontally focussing and defocussing quadrupoles
QT	=	Telescope quadrupoles
B	=	Bending magnets
RF	=	Acceleration cavities
E	=	Experimental areas
SOL	=	Solenoid .

higher energy beams. In addition to electron cooling, stochastic cooling will be provided. Even cooling by inelastic intrabeam scattering of partially stripped ions can be studied.

The main strength of COSY is that it is not only capable to accelerate particles but also to prepare the beam in many different ways. Due to the long storage time of the beam the transverse as well as the longitudinal phase space can be adjusted to the requirements of the experiment. In these respects the ring can be regarded as a phase space transformer. Certainly not all the possible operation modes can be explored at the same time but as the need arises the facility has the potential to be adjusted to a wide range of demands. Some of the expected properties of COSY are summarized in table 1.

Table 1: Survey of COSY beam characteristics for protons

Energy range		20 - 500 MeV (Stage I)
		< 1500 MeV (Stage II)
Acceptance	E_x	200 π mm mrad
	E_z	100 π mm mrad
Emittance, cooled	$E_x = E_z$	0.15 π mm mrad
Momentum resolution for 10^8 stored cooled particles		$< 10^{-4}$
Number of stored particles		
- Injector cyclotron		10^9
- Injector Linac		10^{11}
Circulating beam at 500 MeV		
- Injector cyclotron		0.21 mA
- Injector Linac		21 mA
Extracted beam (without acceleration and cooling)		
- Injector cyclotron		0.015 μA
- Injector Linac (stretcher mode)		1.6 μA

Other properties:
(1) Alternative use of ultrathin internal targets or conventional targets in bypass section. (2) Injection of light ions from the ISIS-JULIC combination. (3) Use of high intensity polarized protons. (4) Storage of exotic light reaction products.

COSY is designed to operate over a wide range of particle energies. The physics to be investigated is quite different in the energy range above 1 GeV where mesonic effects and subnuclear degrees of freedom play the dominant role and between 200 and 500 MeV where new information on nuclear forces and nuclear structure can be gained. For precision measurements at low energies the spectrograph BIG KARL with its unusually high energy resolution is an important tool. The project to build a storage ring started originally with considerations for a beam recirculator to improve the luminosity for measurements with the spectrograph. The recirculator is a storage ring with dispersion matching at the object position of the spectrograph. The mean energy loss in the conventional target of about 50-100 $\mu g/cm^2$ is compensated by an appropriate correction RF with an amplitude of a few hundred electron volts (not shown in fig. 1). The beam quality, however, deteriorates quickly typically within 10^2 - 10^4 turns. For sufficiently thin targets this can be prevented by phase space reduction of the beam through one of the well known cooling methods, electron cooling or stochastic cooling. Stochastic cooling is most efficient for weak beams. For more than 10^8 particles in the ring with currently available amplifier band widths of a few hundred MHz stochastic cooling leads to cooling times of $\gtrsim$ 10 s which are too long for our purpose. For higher intensities electron cooling is more effective, especially when the beam quality is high at the beginning. This poses limits on the emittance blow up by the target. Therefore either very thin targets ($\lesssim$ 0.1 $\mu g/cm^2$) must be used or provisions must be made so that the circulating current passes through a target of standard thickness only once every 100 - 1000 turns. Both operation modes are considered for COSY. The ultrathin targets can be realized as cluster targets or as atomic beam targets. Hydrogen cluster targets have been used at Saclay and CERN. It is proven that they can be made compatible with ultrahigh vacuum in a storage ring. In the case of atomic beam targets even polarization of the target nuclei can be achieved.

To provide an enlarged energy range and greater flexibility with respect to beam preparation the recirculator concept was developed into COSY by adding synchrotron acceleration. Long straight sections were inserted to provide room for the cooling section, the experiments and the elements for injection, diagnosis and beam steering. The bending radius was chosen large enough to focus protons up to about 1.5 GeV at moderate magnetic fields. Whenever possible, stripping injection will be preferred. For experiments with the external beam a slow extraction path will be added. The resulting lattice design is shown in fig. 1. The essential design parameters are summarized in table 2 also showing a particular example of working parameters.

An important feature of the ring are the telescopic straight sections which will be set to a tune shift of 2π. Therefore, manipulations within the telescopes are

Table 2: Parameters of COSY

6 unit cells of the structure QF-B-QD-B-B-QD-B-QF
Two double telescopes of 35 m length each and with magnification M=+1

Circumference:		173.8 m
Bending radius		7.0 m
Dipole field for 500 MeV protons		0.52 T (Stage I)
Dipole field for 1.5 GeV protons (p=2.25 GeV/c)		1.07 T (Stage II)
Free length for cooling section:		4.0 m
Free length for BIG KARL:		3.1 m
Acceptance, for $\Delta p/p=0\%$: $E_z=100\ \pi$ mm mrad		E_x = 223 π mm mrad
for $\Delta p/p=0.2\%$		E_x = 190 π mm mrad
max. $\Delta p/p=0.43\%$		
Emittance cooled:		$E \lesssim 0.15\ \pi$ mm mrad
Dispersion at the target:		variable: 1 m - 20 m
ß-function at the target		variable:0.37-10.25m
frequency range (h = 1)		0.5 - 2.0 MHz
Vacuum:		$< 10^{-9}$ mbar
The following values correspond to the dispersion ‖D‖ = 5 m at the target		
ß-function:	β_{target}:	β_x = 1.7 m
Maxima in the unit-cell:	$\beta_{horizontal}$:	β_x = 19.7 m
	$\beta_{vertical}$:	β_z = 16.8 m
Q-values:		Q_x = 3.11
		Q_z = 3.82
γ_{tr}		1.356

in first order nearly invisible to the ring. For instance, one of them allows adjustment of the desired low values of β_x, β_z, and the dispersion at the position of the electron cooler. With these values a momentum band of ± 0.2 % is accepted for electron cooling assuming a typical electron beam diameter of 2.5 cm. The dispersion at the target can be varied in a wide range with the target telescope to match the experimental conditions. In addition the Twiss parameter α can be varied in a wide range to give the kinematic matching necessary for high resolution particle spectroscopy. All these adjustments are done keeping the advantageous 2π tune shift of the telescopes.

For acceleration two SUSINI type RF-cavities are located in the electron-gun telescopes. These positions have been chosen to match the zero-dispersion crossover point. Skewed quadrupoles will be installed at the ends of both straight sections to ensure sufficient decoupling between the x- and z-planes. Acceleration parameters are given in table 3.

Table 3: Acceleration parameters for protons

	cyclotron injection	examples	
E [MeV]	40	200	1500
Bρ [T•m]	0.924	2.150	7.507
accel.time[s]	-	0.19	1.0
ß	0.283	0.566	0.923
revolution time[μs]	2.061	1.032	0.632
field ramp [T/s]		0.94	

The present design provides the following operational modes:

(a) Recirculator mode
(b) Stretcher mode
(c) Compressor mode
(d) Cooling modes
(e) Acceleration modes

There are essentially three main fields for research with COSY

(1) nuclear structure and reaction mechanism studies as well as the study of the effective projectile-target nucleon interaction
(2) mesonic degrees of freedom
(3) fundamental symmetries and the nucleon-nucleon-interaction.

To conclude, we give a condensed yet incomplete list of experimental methods and research subjects at COSY:

- study of sharp resonances and of threshold energies
- detection of heavy recoil nuclei
- production of tagged secondary beams (in particular neutrons)
- high resolution reaction spectroscopy
- measurement of three particle decays with high coincidence rate
- life-time measurements with very short beam pulses
- experiments with polarized beams and polarized targets
- storage of rare reaction products (e.g. tritons, 6He)

- study of (n,p)-reactions near 0^0 with monoenergetic neutron beams
- polarization transfer experiments, study of the spin-spin interaction with high resolution
- spin excitation in the energy window
- investigation of deep lying hole states
- pion production at the Δ-resonance
- coherent meson production
- threshold behaviour of meson production
- recoilless production of mesons and excitations in nuclei
- recoilless production of tagged low energy pions
- atomic physics studies in ion-ion-scattering
- studies of the nucleon-nucleon-interaction, in particular involving polarization.