EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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PHYSICS III COMMITTEE

LETTER OF INTENTION :

STUDY OF MUONIC X-RAYS AND NUCLEAR γ-RAYS WITH A CRYSTAL SPECTROMETER

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1) Motivation for the installation of a crystal spectrometer

Recent experiments of the Berlin-Darmstadt-Fribourg-SIN group (SC 2a) have shown the feasibility of measuring magnetic hf-splittings of muonic X-rays and nuclear γ-rays in muonic atoms [Baa B 68, Lin B 71]. These data are sensitive to the spatial distribution of the magnetic moment in the nucleus (Bohr-Weisskopf effect). However, in only a few cases the resolution of Ge(Li) detectors would be sufficient to resolve the magnetic hf splitting. For example, the hf splitting of the first excited 2+ state in deformed nuclei is expected to be about 500 eV for 2+-0+ nuclear γ-rays of 100-200 keV. This exceeds the resolution of present Ge(Li) detectors. The 2+ hf-splitting would determine the present unknown Bohr-Weisskopf effect of the g_R factor. For this experiment an energy resolution of less than 200 eV is necessary. For several odd nuclei we expect hf splittings of 10-100 eV which needs a resolution of less than 50 eV. In principle all these measurements can be done with a curved crystal spectrometer. In addition such

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a spectrometer can be used for several other open problems in connection with muonic and pionic atoms: accurate determination of charge radius of light nuclei, test of vacuum polarization and Lamb shift, electron screening in μ and π atoms.

The essential difficulty of these experiments is the extremely small solid angle of the detector which requires high intensities of the sources. A spectrometer of the DuMond configuration which has been developed in Fribourg is described in section 2. The possibility to increase the μ stop density by installing a superconducting solenoid is discussed in section 3.

2. A curved crystal spectrometer of the DuMond configuration

In principle two different constructions can be considered: the Cauchois and the DuMond type. They are symmetric in the sensethat detector and source are exchanged to pass from one to the other arrangement. For this reason they are equivalent under the condition that the specific activity is the same for the small DuMond and the large Cauchois sources, neglecting effects due to background. We intend to use a DuMond type spectrometer, constructed at the University of Fribourg [Bee E 70].This choice is based on the arguments outlined in section 3. Beside the higher specific activity available with the solenoid, the use of a smaller target allows measurements with separated isotopes. The radius of curvature is variable and can be chosen in function of the problem or of practical conditions. The very large angular range (± 20°) of the instrument permits the measurement of low-energy transitions at different order of reflection. Fig. 3 shows the calibration curve of the crystal drive of this angular range. The corrections to be applied to the angular settings are in general less than 1". The calibration is simple and it is possible to correct for defocalisation at large angles. On the other hand a very good mechanical stability between the source and crystal is necessary.

The greatest difficulty, however, is the larger detector, up to about a factor 50 compared to the Cauchois type. As the background fluctuations vary only as the square root of the average counting rate, this should not be too serious, provided special care is taken as regards the shielding.

The best known resolution so far achieved with crystal spectrometers is one second of arc over a surface of a few cm^2. This corresponds to a resolution of 20 eV at 100 keV in first order (Quartz). If a decrease in resolution is permissible, a corresponding gain in luminosity (larger source and crystal) will follow. Table 1 gives some typical data. Measurements with different crystals are under way in order to improve the reflectivity and useful crystal surface.

Table 1

Data of the Fribourg DuMond crystal spectrometer

Mosaic angle spread	10^{11}
Source thickness	0.25 mm
Radius of curvature	5 m
Reflecting surface	20 cm^2
Solid angle	6×10^{-6}
Target	~ 200mg
Stops/sec (SIN)	10^7
Counting rate (1 γ/μ stop)	10/sec

3. The low momentum operation mode of a superconducting solenoid μ channel

A superconducting solenoid as a very efficient μ channel is described in detail in refs. [Pet 70, Pet V 71]. As proposed by Duclos, Prion and Petijean [Duc P 67, Pet 70, Pet V 71] the μ stop density can be improved by using a superconducting solenoid in the low momentum operation mode. In this mode pions of typically 100 MeV/c are focussed on a degrader which is placed at the entrance of the solenoid having an axial magnetic field of about 50 kGauss. The pions entering the solenoid after passing through the degrader have a very low momentum (0-85 MeV/c); they therefore decay almost completely in even a short solenoid of 1-1.5 m yielding low-energy muons which move in spiral trajectories at a very low pitch. By placing the target at the end of the solenoid in the high-magnetic field a high stop density can be achieved in a very thin target (< 0.1 g/cm^2). The estimated parameters and the experimental set-up for a system planned for the SIN [Pet 70] are given in Table 2 and Fig.1. The stopping density as a function of the target thickness is given in Fig. 2.

Table 2

Low momentum operation mode of a solenoid for the SIN

π injection: $p_\pi = 100 \pm 7$ MeV/c

$E_\pi = 32 \pm 4$ MeV

$I_\pi = 0.8 \times 10^9 \pi^-/\mathrm{sec}$

degrader: $d = 3.5$ g cm^{-2} graphit

$p_\pi = 40 - 70$ MeV/c

$E_\pi = 7 - 22$ MeV

π-decay: $p_\mu = 0 - 85$ MeV/c

$E_\mu = 0 - 30$ MeV

$I_\mu = 1.5 \times 10^7 \mathrm{cm}^{-2} \mathrm{sec}^{-1}$

internal μ target : 50×5 mm^2

This system has the disadvantage that a telescope cannot be used in coincidence with the crystal spectrometer. A plastic scintillator in front of the target would stop all muons in this scintillator; in addition the technical problems are rather formidable problems involved in installing a scintillator into the vacuum chamber of the cooled solenoid. The only possibility seems to be to place the counter in front of the degrader. Such a counter would, however, accept all pions and has rather poor time resolution because of the time-of-flight spread for the trajectories in the solenoid. We feel, however, that these disadvantages are not serious since an identification of γ lines can be made by a separated experiment using a Ge(Li) detector and the background can be reduced using big coaxial Ge(Li) detectors instead of NaI crystals.

4. Installation of a solenoid at the improved SC

The intensity of the π beam of the improved SC will be about a factor 10 smaller than the intensity of the SIN. But even scaling down all intensity numbers in Table 1 and 2 by a factor 10,experiments with a crystal spectrometer in connection with a solenoid are feasible for several selected experiments. Therefore, we intend to install a 1.5 m-long superconducting solenoid at the extracted proton beam of the SCIP. This short solenoid is under construction as a prototype for the 10 m-long SIN μ-channel.

With this section we can study problems of the future SIN μ-channel before the SIN is in operation and several selected experiments can be performed already at CERN. The technical details of the installation will be discussed and if no unforeseen unresolvable difficulties occur we shall submit detailed proposals for this project in the beginning of 1972.

REFERENCES

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Pet V 71	C. Petitjean and G. Vécsey: paper submitted to the 1971 Particle Accelerator Conference, March 1-3, Chicago.
Pet 71	C. Petitjean: paper submitted to the Muon Physics Conference, Fort Collius, Colorado, Sept. 6-10, 1971.

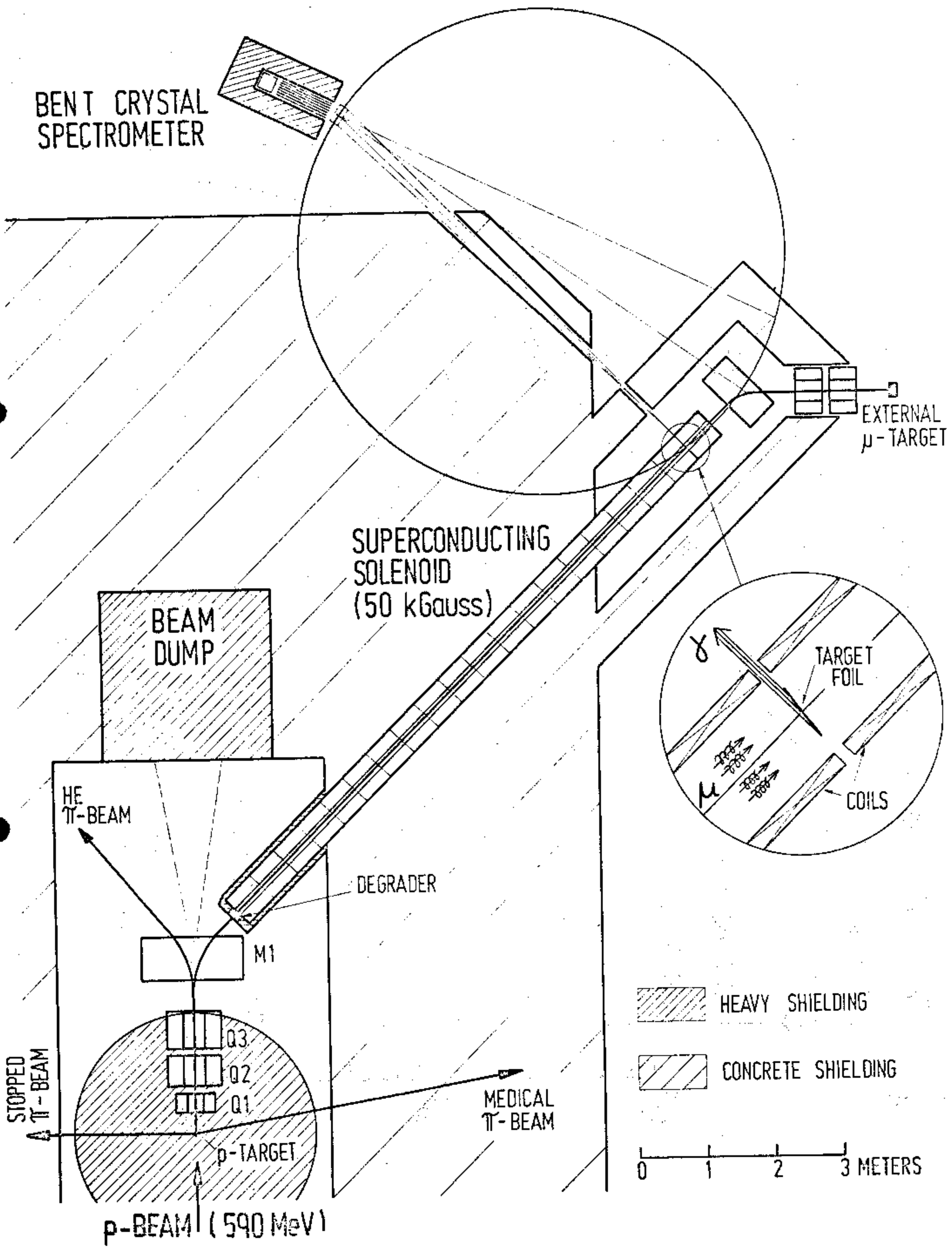

BENT CRYSTAL SPECTROMETER
EXTERNAL μ-TARGET
SUPERCONDUCTING SOLENOID (50 kGauss)
BEAM DUMP
γ
TARGET FOIL
μ
COILS
HE π-BEAM
DEGRADER
M1
Q3
Q2
Q1
STOPPED π-BEAM
MEDICAL π-BEAM
p-TARGET
p-BEAM (590 MeV)
HEAVY SHIELDING
CONCRETE SHIELDING
0
1
2
3 METERS

Fig.1

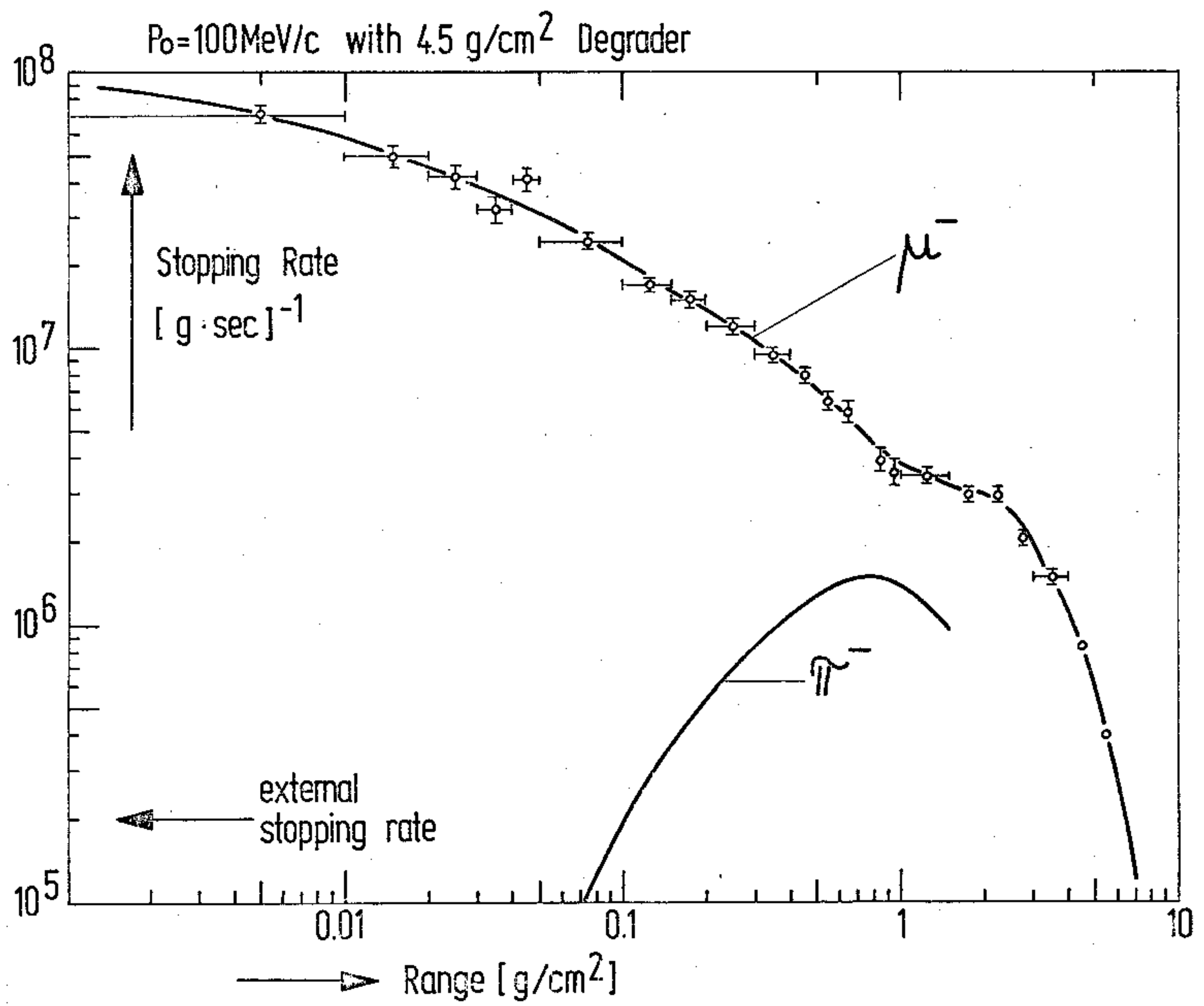
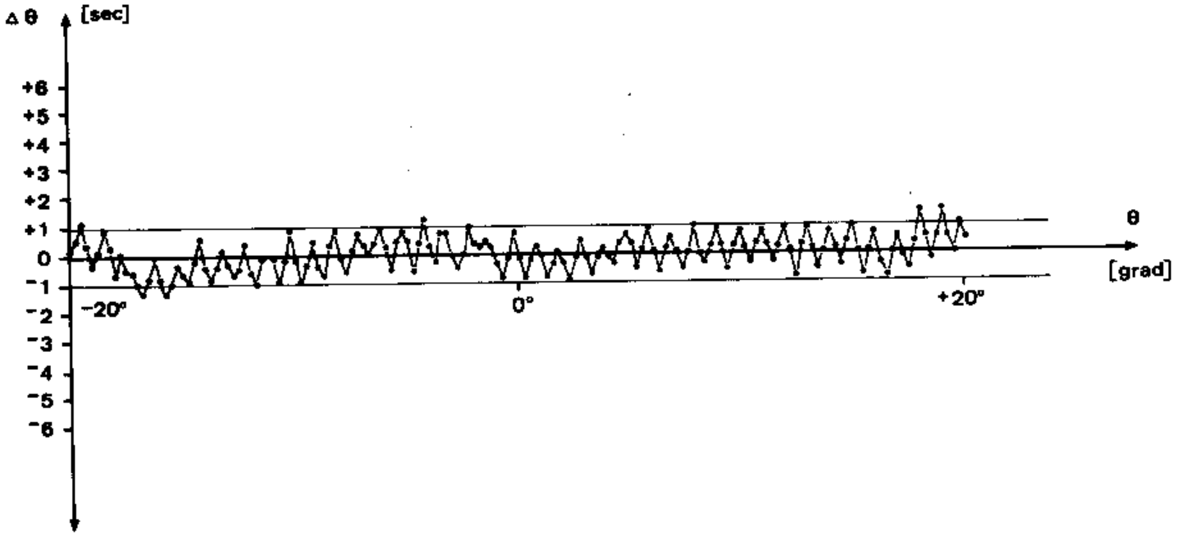

Po=100MeV/c with 4.5 g/cm2 Degrader
Stopping Rate
[g · sec]-1
10^8
10^7
10^6
10^5
μ-
π-
external
stopping rate
0.01
0.1
1
10
Range [g/cm2]

Fig. 2



Eichkurve des Kristallantriebes

Fig. 3