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Dicembre 1970

C. Schuhl: THE SACLAY'S HIGH DUTY CYCLE LINAC: PERFORMANCES OF THE MACHINE, EXPERIMENTAL FACILITIES AND FIRST EXPERIMENTS. -

"Frascati Meeting on Electronsynchrotron"
Frascati, November 5-7, 1970

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Invited talk, given at the
"Frascati Meeting on Electronsynchrotron"
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C. Schuhl(x): THE SACLAY'S HIGH DUTY CYCLE LINAC(o): PERFORMANCES OF THE MACHINE, EXPERIMENTAL FACILITIES AND FIRST EXPERIMENTS. -

1. - THE LINAC PERFORMANCES. -

The Linac has 30 sections powered by 15 klystrons with 8 modulators. The duty cycle is 1% or 2% obtained by 10 μsec pulses and 1000 Hz or 2000 Hz for repetition rate.

The total length of the accelerating structure is 180 meters (6 meters sections). Between the sixth and the seventh sections a converter e^-/e^+ is installed; the positrons are accelerated in the 24 following sections.

From january 1970 to the end of august, about 1000 hours of useful beam for nuclear and particle physics experiments were provided during 2000 hours of operation. This relatively low rate of disposal of the beam is mainly due to the difficulties in operating the positron beam. Normal beam has a yield of 80%.

(x) - Service de Physique Nucléaire à Haute Energie, Centre d'Etudes Nucléaires de Saclay.

(o) - There are two departments for the Linac: one for the machine and the other for physics. The names of these departments are the following: Service de l'Accélérateur Linéaire (Chef du Service: F. Netter), Service de Physique Nucléaire à Haute Energie (Chef du Service: C. Tzara).

Fig. 1 shows the installations. A low energy station is provided between section 12 th and 13 th. At the end of the 30 th section the beam is available in three experimental areas: HE3, HE1 and HE 2 rooms, and the pion and muon sources.

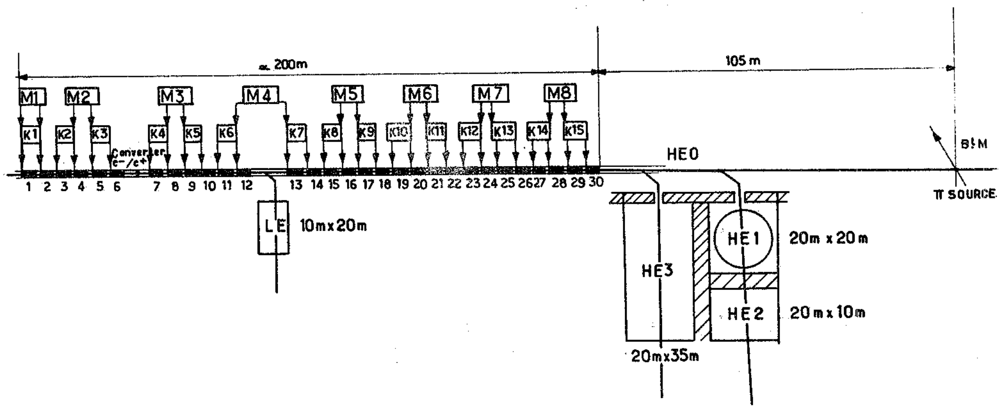


FIG. 1 -. Linac and experimental areas arrangements.

Negaton characteristics.-

Maximum unloaded energy(x):	640 MeV
Slope:	2.75 MeV/mA
Emittance measured at the end of the machine at 400 MeV:	2×10^{-5} cm. r.
Diameter of the beam :	5-6 mm
Energy spectrum:	100% in a 0.5% width 80% in a 0.3% width 50% in a 0.15% width

Beam stability is very good and electron energy down to 200 MeV has been achieved for electron scattering experiments in the HE 3 room.

The machine is able to give 40 mA peak current (400 μA average) of 500 MeV negatons. During trials in 1969, 100 kW beams have been operated for hours as well as recently for pion production.

All these performances of the machine are very important: the maximum beam current is necessary for the pion source and muon beam; good energy resolution and emittance enable us to get more beam on the target for high resolution scattering work; high duty cycle is crucial for the coincidence experiments we are performing.

(x) - This energy is obtained when all the conditions are optimum. The "normal" maximum unloaded energy is around 580 MeV.

Positron beam.-

a) The maximum yield obtained once for a 470 MeV positron beam at the end of the Linac is 1.3×10^{-3} having 26 mA negaton peak current (260 μA average) at about 80 MeV on the conversion target, we measured 36 μA positron peak current (360 nA average).

For people having the habit of speaking in number of particles per pulse, 36 μA positron peak current corresponds to 2×10^9 e^+/pulse i.e. with a 1000 Hz repetition rate 2×10^{12} e^+/sec.

With an 1% energy band width we detected 75% of the total positron current id est 27 μA peak intensity (either 270 nA average or 1.5×10^9 e^+/pulse).

b) In a long run our results were limited at negaton beam peak current between 10 and 20 mA (100 to 200 μA average) on the conversion target, giving us the typical positron beams we used for experiments.

E_+ (MeV)	I_+ mean current after 1% slits (nA)	I_- mean current on the converter (μA)
470	70	88
300	50	130

We have some difficulties with the conversion target and the head of the 7 th section which follows the converter and receives the showers created in it. The longest lifetime we had till now for converters was 130 hours.

2.- THE BEAM HANDLING SYSTEM (HEO AREA) (Fig. 2).-

The standard beam handling system into the first experimental area (HE 3) is composed of a small magnet E 2, two deflecting magnets B 1 and B 2 with a quadrupole Q_2 between them and a slit F_2.

The dispersion at the slits is 3 cm per 1%.

Sensitive ferrite current monitors and fluorescent screens are used to control the beam throughout.

The magnetic field in the B 1. B 2 system is adjusted using a nuclear magnetic resonance probe.

The first beam was obtained in HE 3 in march 1969 and the whole system has been operating very satisfactorily.

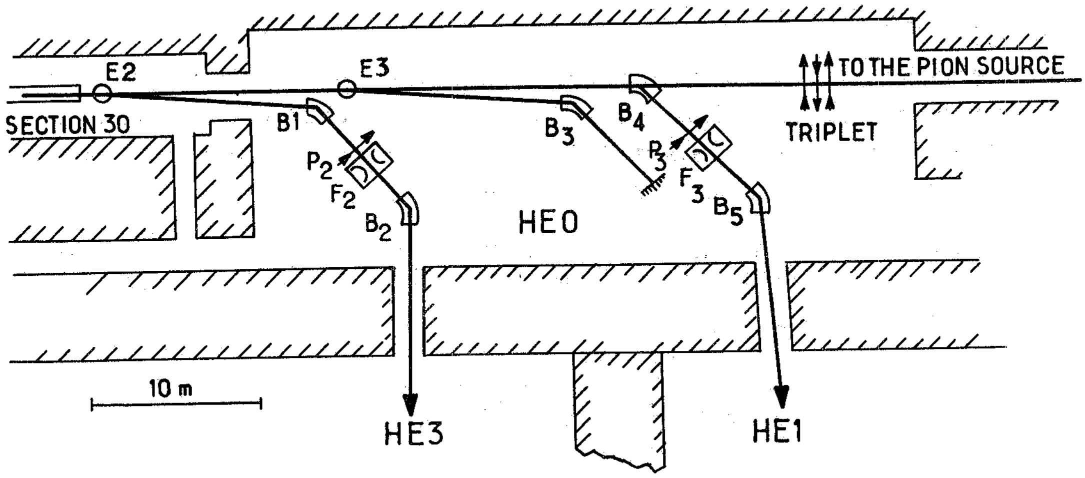


FIG. 2 - The beam handling system.

An almost similar diflecting system (two magnets B4, B5 a quadrupole Q_3 and a slit F_3) will be installed to send the beam in the experimental room HE 1.

The beam is directed into the pion experimental area (Bt. M) located at 105 m from the end of the machine in straight line, using only a focusing quadrupole triplet. First pion and muon beams from the pion target were obtained in july 1970. Trials at high beam power were successfully made in november 1970.

Nota: A small magnet E 3 and the magnet B 3 can be used to analyse the beam energy spectrum.

3. - THE FIRST EXPERIMENTAL AREA (HE 3). -

Photonuclear reactions (see also P. Argan talk). -

The photonuclear set up permits us to obtain either bremsstrahlung or monochromatic photons by annihilation in flight of positrons (see Fig. 3).

The electron beam (e^- or e^+) is focused on the bremsstrahlung or annihilation target with the quadrupole doublet Q_6 - Q_7 which lies in the wall between HE 0 and HE 3.

A sweeping magnet (aimant balai[(x)]) deflects the electrons (negatons or positrons) beam into a Faraday cup which is used for monitoring the intensity. The photon beam go through an hole in the magnet,

(x) - Characteristics of all the big magnets are resumed at the end of this paper.

an iron and lead collimator and after having crossed over the photonuclear target is measured by a Type Wilson quantameter.

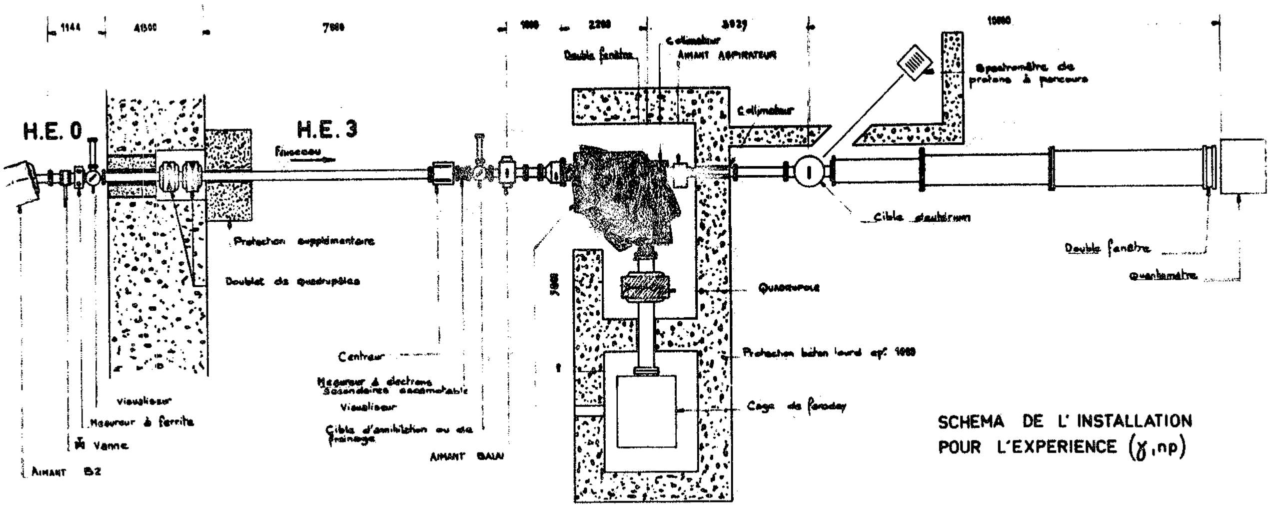


FIG. 3 - Photon sources.

At about 300 MeV, the annihilation photon intensity was of the order of 10^8 gamma per second on the $\emptyset = 5$ cm photonuclear target located at 6 meters from the annihilation lithium target. Till now we used for annihilation and bremsstrahlung 10^{-2} radiation length targets (10 mm Li or 0.15 mm Cu).

The energy resolution is function of the positron energy width, of the ionization energy losses of the incident beam in the annihilation target, of the multiple scattering and the energy angular dependence of the annihilation process. In our experimental conditions the energy width of the monochromatic photons was around 4 MeV. This value is obtained theoretically.

We proposed to study high energy photoproton emission from ^{16}O in the (3.3) resonance region.

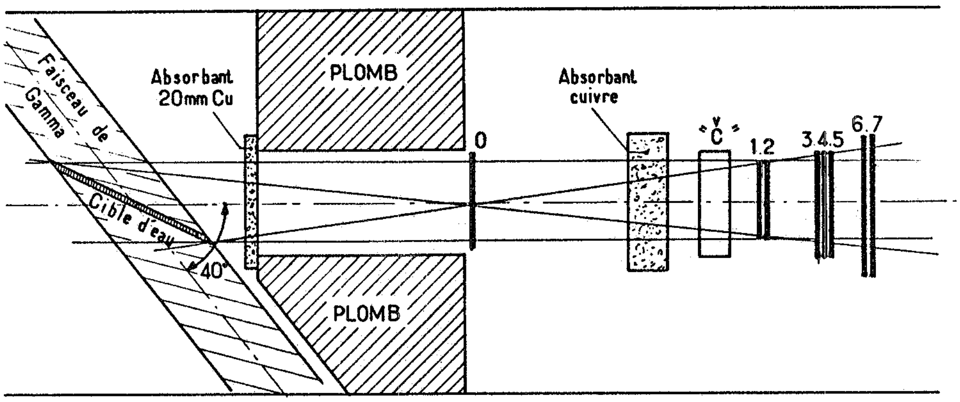
The photoprotons are detected in two identical range detectors placed at 40^{o} and 90^{o} of the incident photon beam.

A telescope (Fig. 4) consists of 8 scintillators, a lucite Cerenkov and two copper absorbers. Four energy channels are defined with an experimental resolution of 4.5 MeV at 200 MeV.

The background corresponds to about 0.1 μb/sr and 0.015 μb/sr at 40^{o} and 90^{o} respectively.

Fig. 5 shows the proton energy spectra we obtained at 243 MeV with positrons (annihilation in flight + bremsstrahlung) and with negatons (bremsstrahlung only). This first result was obtained in about 5 hours.

We stopped because the converter trouble.



– La collimation de plomb est large – L'angle solide est défini par la cible d'eau et le scintillateur n°2 ECHELLE : 1/5 10cm	SCINTILLATEURS	EPAISSEUR	DIMENSIONS
	0	5mm	100 x 110 mm2
	1 et 2	5mm	110 x 110 mm 2
	3,4 et 5	2mm	150 x 150mm2
	6 et 7	5mm	200x200mm2
	ČERENKOV	40 mm	150 x 150mm2

FIG. 4 - Photoproton detector.

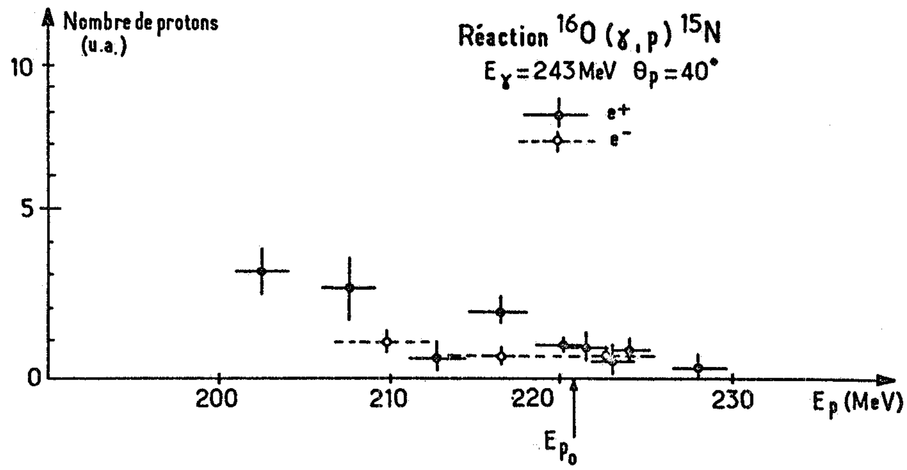


FIG. 5 - Photoproton spectrum on ^{16}O at 243 MeV.

Fig. 6 shows the results we had when we detected pions (π^+ and π^- together) in the range detector. At 279 MeV the ranges of photopions and photoprotons emitted from ^{16}O are the same.

We also planned to study (γ,π), (γ, pn), (γ, pp) and (γ, pπ) reactions. An Orsay group (P. Radvanyi et al.) are preparing the study of the reaction $^3He(\gamma,\pi)^3T$.

Electron scattering and coincidence experiments.-

Two analysing magnets are now installed on a "Carrousel" (Fig. 7) (Merry-go-round):

- a magic angle spectrometer, 400 MeV/c for electron scattering
- a 90° spectrometer, 700 MeV/c for coincidence works,

both have heavy shielding around the focus planes.

The first electron beam on the electron scattering target was obtained in January 1970.

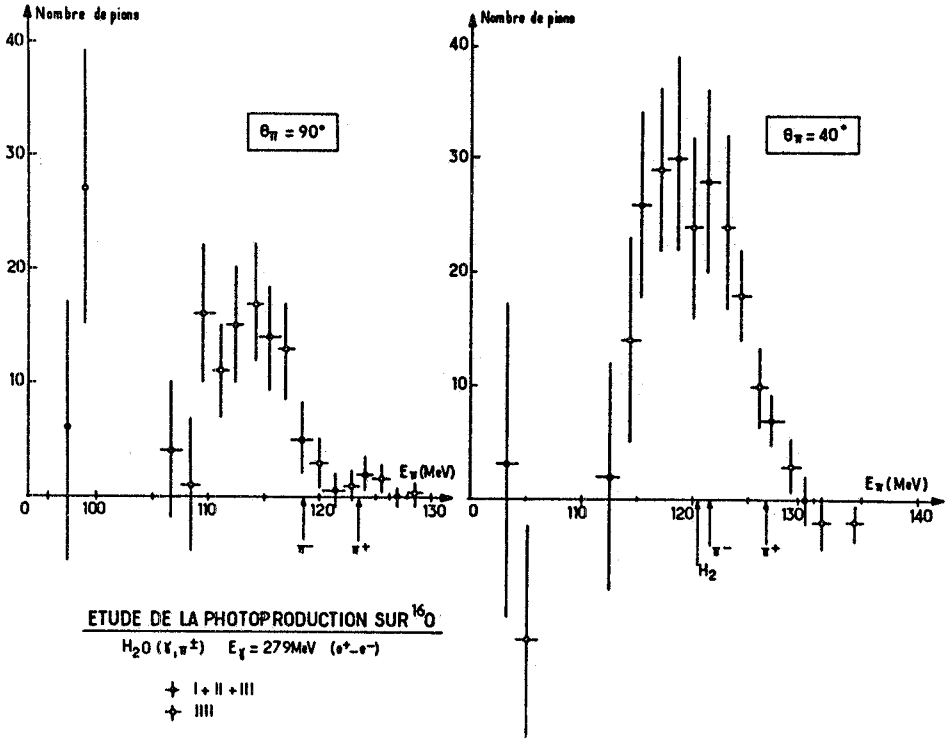


FIG. 6 - Photopion spectra on ^{16}O at 279 MeV.

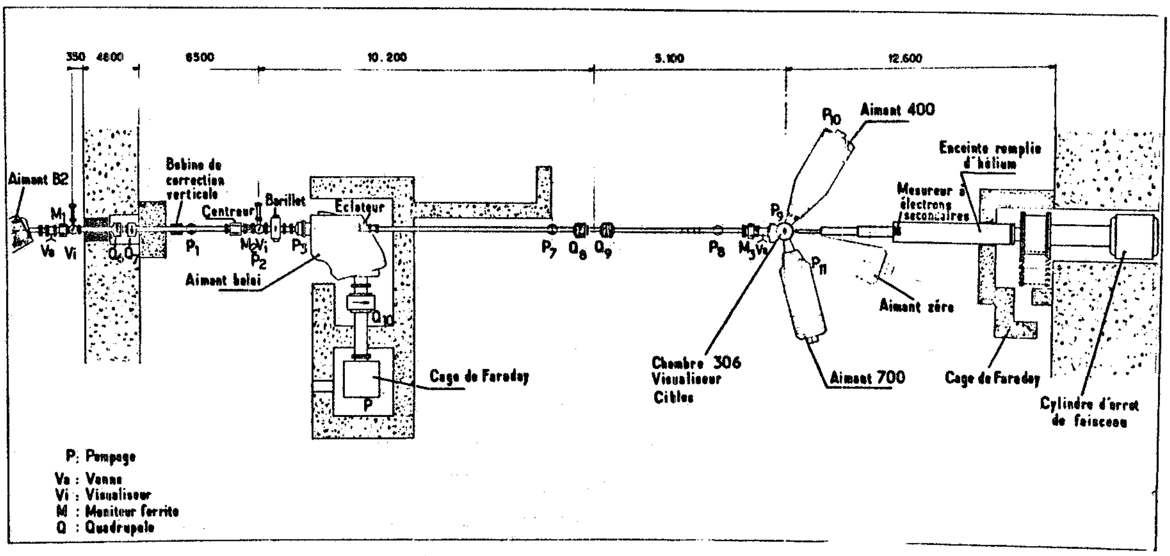


FIG. 7 - Carrousel arrangement with the first "two magnets".

The first experiment was a check, at 375 MeV, of the elastic scattering on ^{12}C up to 90^o to compare with recent Stanford data (Fig. 8). The electron detector, placed in the focal plane of the 400 MeV/c spectrometer, was a channel solid state ladder counter, which has been operating very successfully with an on-line PDP 8 computer. The best resolution we achieved is of the order of 0.1 per 100. The lowest cross section we can measure up to now is of the order of 10^{-35} cm^2/sr. The study of elastic and inelastic scattering by the N = 50 nuclei is begun. Figs. 9 and 10 show the results obtained on ^{90}Zr and ^{92}Mo.

In August 1970, preliminary experiments on quasi-elastic scattering $^{12}C(e, e'p)^{11}B$ are underway with the two spectrometers 400 and 700 and two 30 channels scintillator ladder counter to detect in coincidence the electrons and the protons. The overall resolution is about 3 MeV. An experimental spectrum obtained after a two hours run is shown on Fig. 11.

A third plateform is provided to receive a third magnet (AIMANT ZERO) to study π^+ and π^o electroproduction on hydrogen. This magnet can attain angles as little as 9^o.

4. - THE SECOND EXPERIMENTAL AREA (HE 1). -

Electron scattering with high resolution and coincidence equipment will be installed in the HE 1 room.

In (ee'x) reactions, heavy particles have to be detected and their momenta can reach values greater than the electron one. For this reason we decided to build a 900 MeV/c spectrometer so-called "900". It will be complementarily used at low field for high resolution electron scattering. Under 600 MeV/c, no saturation effect destroys resolution which is better than 2×10^{-4}.

The second magnet called "600" detects particles up to 600 MeV/c. It has a very large momentum acceptance: 0.70 P_o to 1.10 P_o.

These two apparatus rotate around the same vertical axis. One of the magnet ("900") is bended down (on a 10 m diameter hole) and the second one ("600") is up (Fig. 12).

The spectrometers are now completed and are under magnetic measurements in the factory at Zürich.

In the whole system it is not only necessary to detect energy but also scattering angles θ and ϕ on both spectrometers to know the momentum of the particle x in the nucleus. The only way cheap enough are the proportional wire chambers. Using electronegative gas (ethyl bromide) it is possible to limite the sensitive volume to a little cylinder (ϕ = 2 mm) around the wires.

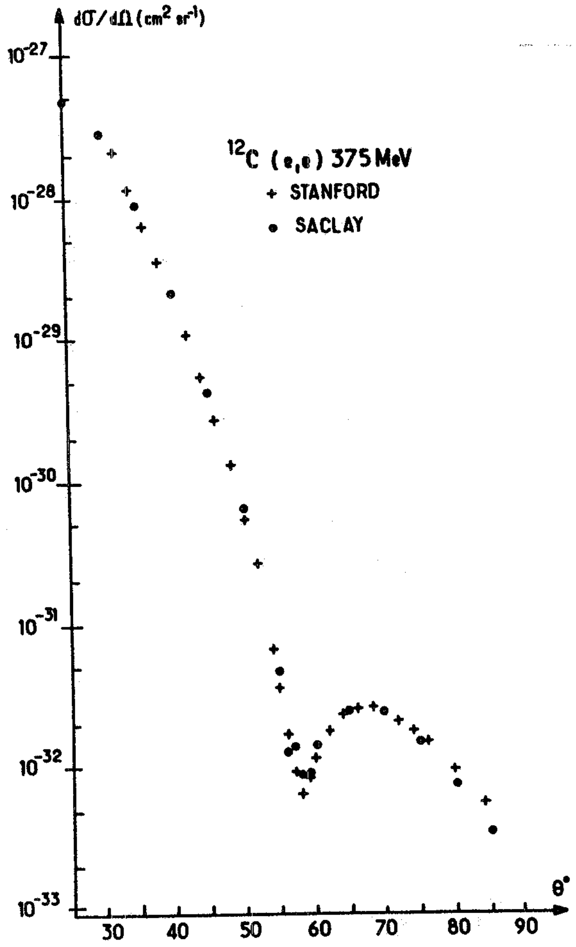


FIG. 8 - Elastic electron scattering on ^{12}C at 375 MeV. The crosses are the results of J. Heisenberg and I. Sick at Stanford. The points are those of Saclay group.

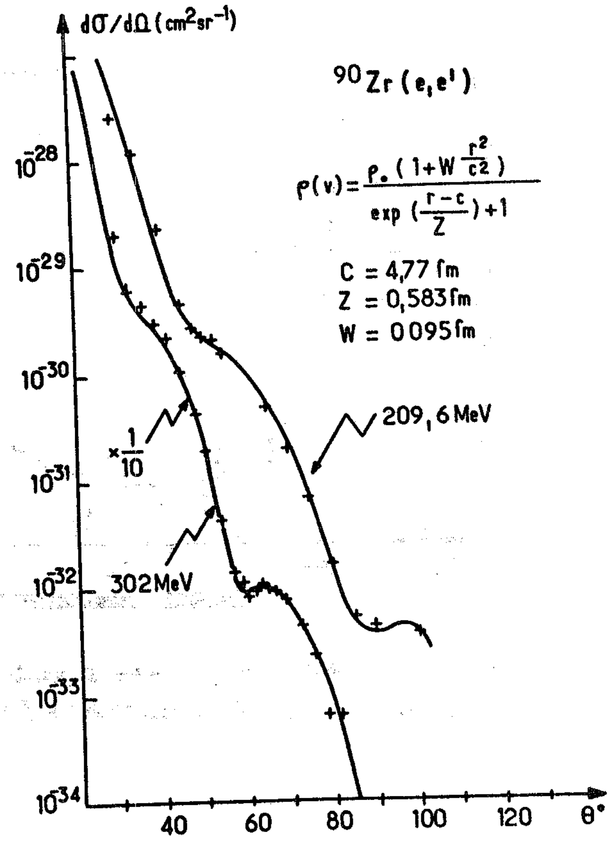


FIG. 9 - Elastic electron scattering on ^{90}Zr at 209.6 MeV and 302 MeV.

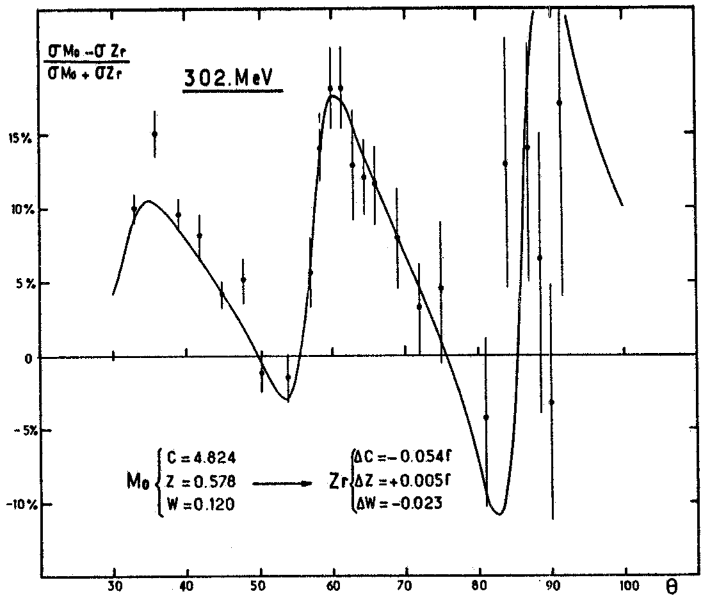


FIG. 10 - Difference between elastic scattering in ^{90}Zr and ^{92}Mo. Electron energy: 302 MeV. The curves are calculated with a 3 parameter Fermi model. (^{92}Mo: C = = 4.824 fm; Z = 0.578 fm; W = = 0.120 ⇒ ^{90}Zr: ΔC = - 0.054 fm; ΔZ = + 0.005 fm; ΔW = - 0.023).

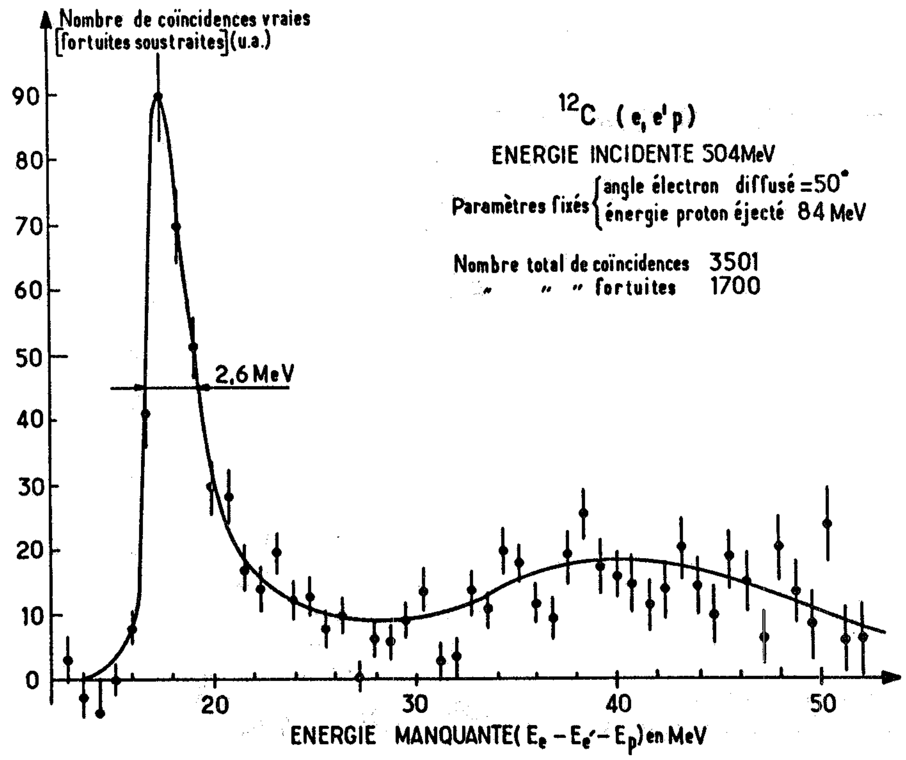


FIG. 11 - Missing mass spectrum for the reaction $^{12}C(ee'p)\,^{11}B$. The curve is fitted by-eye.

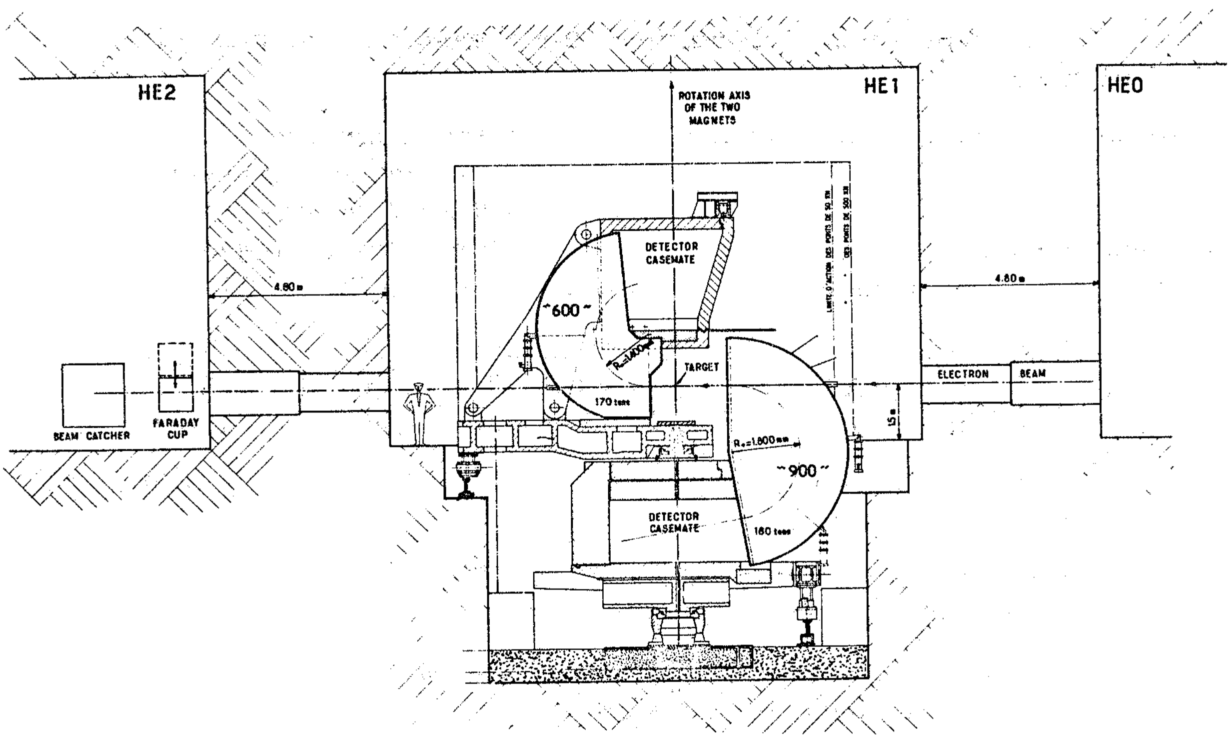


FIG. 12 - Coincidence experimental set-up "900" and "600" magnets. (Vertical section).

5. - PION EXPERIMENTAL AREA (M BUILDING). -

The electron beam handling system consists of a single triplet of quadrupole focusing beam on the pion production target located at 105 m from the end of 30th section. The triplet is placed at midway. More than 90% of the 400 MeV electron current is focused in a 5 mm diameter spot.

First measurements have been started in July 1970 on the pion channel. The cooled target was not yet used, the beam current was limited to 1 μA average current. The pion channel is shown on Fig. 13.

In November 1970 trials were performed with 300 μA negatons of 420 MeV energy on the copper target (126 kW in the beam) which held to this treatment during hours.

There are 9 quadrupoles Q_1 between two 60^o bending magnets A_1 and A_2. The exit slit F 2 at the second magnet defines the moment acceptance of the channel which can attain $\Delta p/p = 5\%$. The two quadrupoles Q_{20} focuse the pion beam on the target.

To decrease the electron contamination, the pions are collected at 120^o from the incident electron beam within 16 msr in the channel, the length of which is 8 meters.

The experimental conditions for measuring the pion yield were the following:

- negaton beam from the Linac : 5 mm diameter
  $1 \mu A$ average current
  420 MeV energy.
- electroproduction target : 10 mm thick copper.
- momentum acceptance of the channel: $\Delta p/p = 3\% (\pm 1.5\%)$.

The maximum yield (Fig. 14) is obtained for 75 MeV pion energy. The $3 \times 10^3 \ \pi^+ \ sec^{-1} \mu A^{-1}$ would give $\simeq 10^6 \ \pi^+ \ sec^{-1}$ for $300 \mu A$ incident electron beam and $\simeq 2 \times 10^6 \ \pi^+ \ sec^{-1}$ for $600 \mu A$ incident electron beam.

The yield of muons produced by the in-flight decay in the quadrupole channel was measured.

For backward decay 40 muons of 75 MeV/c are stopped per second and micro-ampere in 1.2 g/cm^2.

For forward decay 120 muons of 100 MeV/c are stopped per second and micro-ampere in 3.3 g/cm^2.

If $600 \mu A$ can be used, these numbers become 25.000 muons stopped in 1.2 g/cm^2 and 75.000 muons stopped in 3.3 g/cm^2.

One of the first experiments done with the pion beam will be the study of pion scattering on hydrogen.

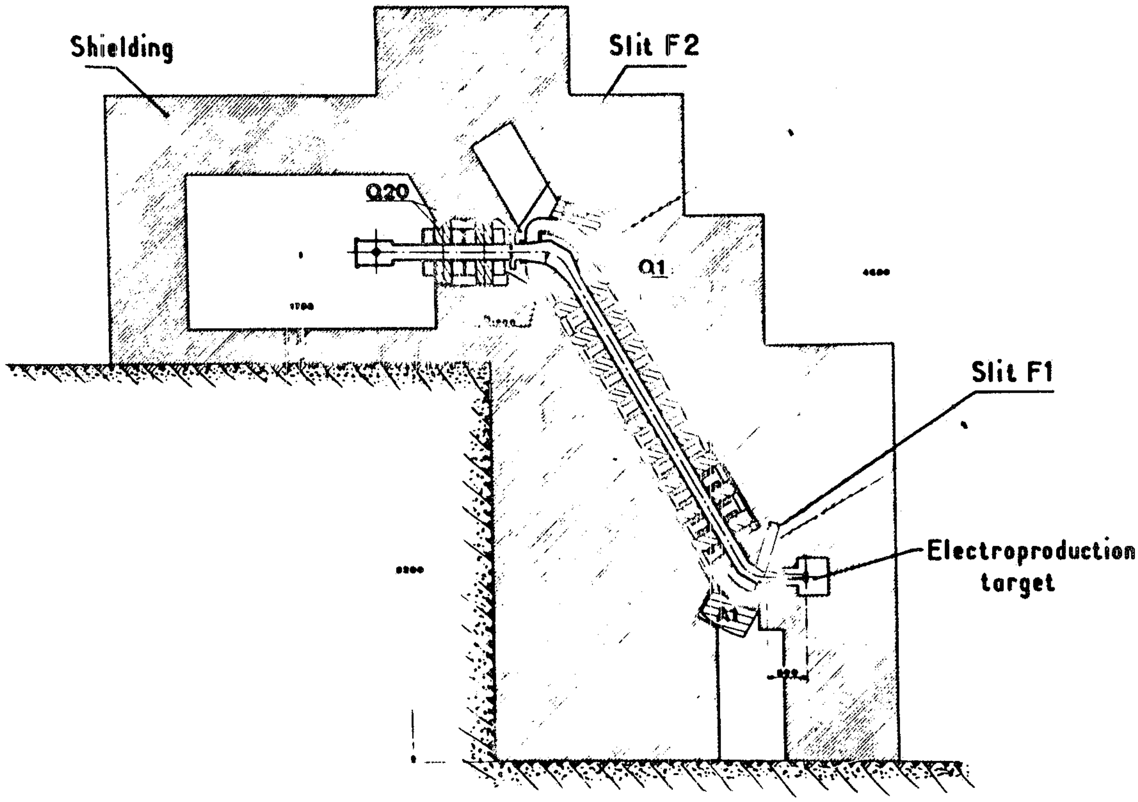


FIG. 13 - Pion channel.

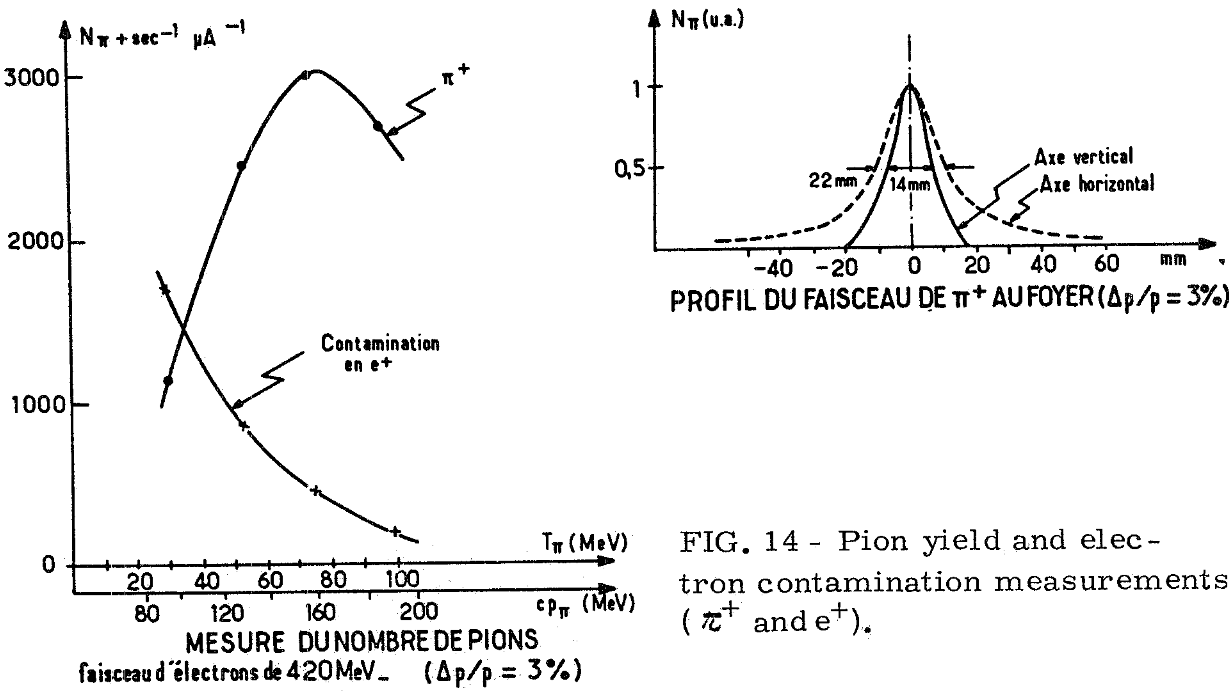


FIG. 14 - Pion yield and electron contamination measurements (π^+ and e^+).

MAGNETS CHARACTERISTICS							
NAME		BALAI	400	700	ZERO	600	900
MAXIMUM MOMENTUM	MeV/c	600	400	700	400	630	900
MAXIMUM INDUCTION	Tesla	1.5	1.5	1.6	1.5	1.5	1.67
FIELD INDICES	n ; β	1/2 ; 1/4	1/2 ; 1/4	0	1/2 ; 1/4	1/2 ; 3/8	1/2 ; 1/6
MEAN TRAJECTORY RADIUS (R_o)	mm	1414	1000	1350	1000	1400	1800
MAGNETIC DEVIATION ANGLE	degree	90	127°16'45" (*)	90°	64°	153°	169°42'
OBJET DISTANCE	mm	1000	2000	1500	1500	700	1470
IMAGE DISTANCE	mm	parallel beam	1000	1170	parallel beam	1400	1470
FOCAL PLANE ANGLE	degree	--	60°	35°	--	36°	40°
MAGNETIC GAP (AT R_o)	mm	100	100	100	120	80	120
USEFUL WIDTH OF POLAR PIECES	mm	150	300	300	160	140 (**)	650
SOLID ANGLE ADMITTANCE	msr	5	4.3	2.8	3 (***)	6.5	2.5 to 5.6
MOMENTUM RESOLUTION (FOR PONCTUAL SOURCE)	per thousand	1	1.1	1		1.5	0.2
MOMENTUM ADMITTANCE	in P_o	0.975 to 1.025	0.97 to 1.03	0.95 to 1.05	0.97 to 1.03 (†)	0.7 to 1.1	0.95 to 1.05
MINIMUM ANGLE OF ANALYSED BEAM	degree		16	20	9	33	25
MAGNET WEIGHT	ton	22	32	42	7.7	170	180
TOTAL ELECTRIC POWER	kW	102.5 (244V-420A)	108 (258V-420A)	135.2 (260V-520A)	152 (280V-542A)	122 (196V-620A)	280 (390V-695A)
WATER FLOW	liter/mn	37	39	49	55	70	202

(*) i.e. $\pi/\sqrt{2}$

(**) At the entrance of the magnet

(***) $\theta_r = \pm 32$ mr ; $\theta_T = \pm 23$ mr

(†) With $\Delta\Omega = 2.5$ msr one can have 0.95 to 1.05 P_o.