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VAMOS : a VAriable MOde high acceptance Spectrometer

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The study of reactions induced by the future SPIRAL beams at GANIL requires new techniques: the low intensity of secondary beams implies the need of a very high efficiency detection system ; the study of nearly or completely unknown nuclei, over a wide range of masses and energies, needs a very efficient method for attributing a reaction product to a nucleus. The VAriable MOde high acceptance Spectrometer VAMOS is being designed and built especially for this purpose.

1. MAIN SPECIFICATIONS

The SPIRAL facility will lead to the availability of radioactive ion beams with intensities several orders of magnitude below those of stable beams. This implies that new detection techniques with very high efficiencies will be necessary. The study of nearly or completely unknown nuclei, over a wide range of masses and energies, needs a very efficient method for attributing a reaction product to a nucleus. As the most intense secondary beams of SPIRAL have a low mass (A<40), it will be necessary in most cases, to work with direct kinematics. In these case the velocity of the composite system is low, and the reaction products cover a large angular cone.

It therefore appeared that tagging of the reactions will be a necessary tool for using the SPIRAL beams efficiently. The union of these characteristics allowed to define a new type of spectrometer having a solid angle an order of magnitude greater than those existing and with different operating modes, combinig a good resolution spectrometer with a velocity filter allowing either M/Q dispersion or rejection of the beam for 0° measurements and also with a focusing without dispersion operating mode similar to a solenoid.

The following main requirements were taken into account in designing the spectrometer:

- A very large geometrical angular acceptance, of the order of 100 msr, which is equivalent to an anglular acceptance of ± 160 mrad in both plans
- A nominal momentum dispersion of about 2cm % at the focal plane
- A momentum acceptance of the order of ± 5 %
- A velocity filter function

Additionally it will be possible to rotate the spectrometer around the target point up to an angle of ≈ 90° and to small negative angle ≈ -5°, and have a large useful space around the target to install an assembly of detectors in coincidence with the detection on the focal plane.

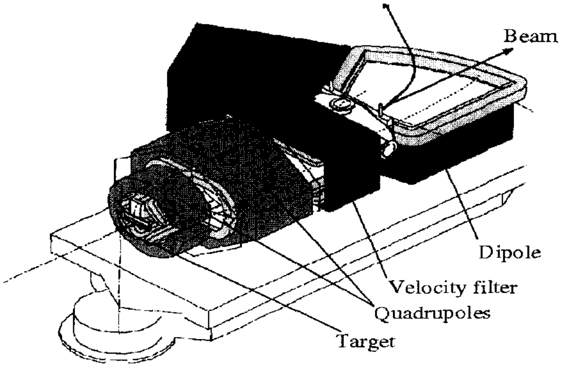

Figure 1. Overview of the Vamos design.

2. ION-OPTICAL COMPONENTS

The VAMOS is a QQFD (quadrupole doublet, Wien filter and dipole magnet) spectrometer. Figure 1 represents an overview of the spectrometer where the different elements discussed below are identified. The ion-optical configuration of this arrangement is listed in Table 1.

2.1 Magnetic quadrupoles

Both quadrupoles have a rather large aperture gaps in order to allow for a high angular acceptance of the spectrometer. The diameter of the first quadrupole is 30 cm while the aperture of the second is elliptical (Collins type) with its major axis around 100 cm. Since the magnetic length of Q1 is only 60 cm a rather strong gradient for the magnetic file is requiered (6.7 T/m). The magnetic length of Q2 is 90 cm with a gradient of 2 T/m. The system is designed to be stigmatic focusing at 1.5 m downstream of the exit of the dipole magnet. The first quadrupole focuses the beam in y-direction, i.e. perpendicular to the plane of dispersion, whereas the second quadrupole focuses it in x-direction, i.e. in the dispersion plane.

2.2 Wien filter

The solution chosen for the electrostatic device is a Wien filter offering the possibility of a pure Wien filter operation (dipole switched off), and conserving the general optics of the spectrometer. The position for the Wien filter is between the Q-pole doublet and the dipole, where the beam is essentially parallel. The length is around 1m, and priority is given to the horizontal deflection, that allows for the M/Q dispersion mode.

2.3 Magnetic dipole

The dipole magnet has a nominal radius of deflection of ρ_{nom} = 1.5 m. Thus a magnetic pole tip flux density of B_{nom} = 1.1 T is required for the nominal maximum magnetic rigidity of 1.6 Tm. The angle of deflexion is variable between 0° and 60°. The entrance and exit field boundaries of the dipole magnet are at angle of 20° and 30°, with a curvature of R_1 = 5 m and R_2 = 3 m to reduce second order image aberrations. Since the beam is kept narrow in y-direction, a gap of 15 cm of the dipole magnet is sufficient.

Table 1. Vamos dimensions and capabilities

Magnetic lenses	Q1	Q2
Magnetic length	0.6 m	0.9 m
Aperture diameter	$2G_0$ = 300 mm	Elliptic
		horizontal : A = ± 500 mm
		usefull height ± 50 mm
Magnetic field on the pole	1.0 T	1.0 T at ± 500 mm
Wien Filter		
Magnetic length	1 m	
Gap width	150 mm	
Maximum electric filed	± 150 kV	
Maximum magnetic filed	0.2 T	
Dipole		
Radius of deflection	1.5 m	
Deflection angle	0° - 60°	
Usefull area for $dB/B = 10^{-3}$	entrance : ± 340 mm (20°<Φ<60°, Bmax)	
	exit : ± 150 mm	
Useful gap	150 mm	
Dipole gap	$2G_0$ = 200 mm	
Maximum field	1.1 T	
Magnetic length	1.57 m	
Inclination of the entrance	20°	
Inclination of the exit	30°	
Curvature of the entrance	5 m	
Curvature of the exit	3 m	
System characteristics :		
Flight path length	7.3 m	
Maximum solid angle	100 msr	
Mass energy product	160	
Energy resolution	1000	
Energy range	20 %	

2.4 Variable modes

The distance between the spectrometer and the target is variable. This has two aims: to increase the flexibility for the use of ancillary detectors, and to be able to accept high magnetic rigidities. The minimum distance of 40 cm between the first Q-pole and the target gives the maximum solid angle of the device, about 100 msr, and a $B\rho_{nom}$ = 1.6 Tm. At a distance of 1 m the $B\rho_{max}$ goes up to 2.3 Tm, and the solid angle is still 40 msr. A maximum distance of 1.4 m will be possible.

Table 2. Different operation modes of VAMOS

Mode	Elements	In Operation	Function
1	Q-poles Dipole Filter	yes no no	Large acceptance non dispersive
2	Q-poles Dipole Filter	yes yes no	Dispersive facility
3	Q-poles Dipole Filter	yes yes yes	Mass spectrometer

Depending on the coupling of the magnetic and electrostatic elements, several operating modes are possible, due to the QQFD structure. This consequently provides a great flexibility and the possibility of adaptation to a broad range of experiments. Table 2. gives an overview of different possible operations of the spectrometer.

2.5 Ion optical calculations

Ion-optical studies have been performed using the 3rd order ion-optical code GIOS and the code ZGOUBI including TOSCA field maps for each magnetic elements.

Figure 2 shows the beam profile along the incident beam line, for the spectrometer operated in the dispersive mode with an initial phase space of $\varepsilon_{x,nom} = \varepsilon_{y,nom} = \pm$ 1.5 mm*160 mrad.

Since the VAMOS spectrometer will have a large angular acceptance, geometrical 3rd-order image aberrations (x/θ^3) will become of high importance and will affect considerably the resolution. The large phase space makes the correction process difficult and complex. The conventional correction of aberrations with higher order hardware (sextupoles, octupoles, etc), in the case of VAMOS, will limit the maximum solid angle and energy acceptance. However, one can reduce significantly geometrical aberration by modification of the shape of Q2 pole in

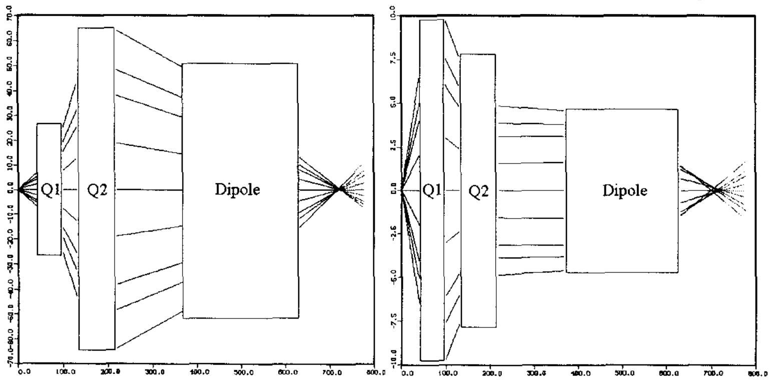

Figure 2. Space optics of the VAMOS spectrometer operated in the dispersive mode. Left : beam envelop in the horizontal plane, right : same for vertical plane.

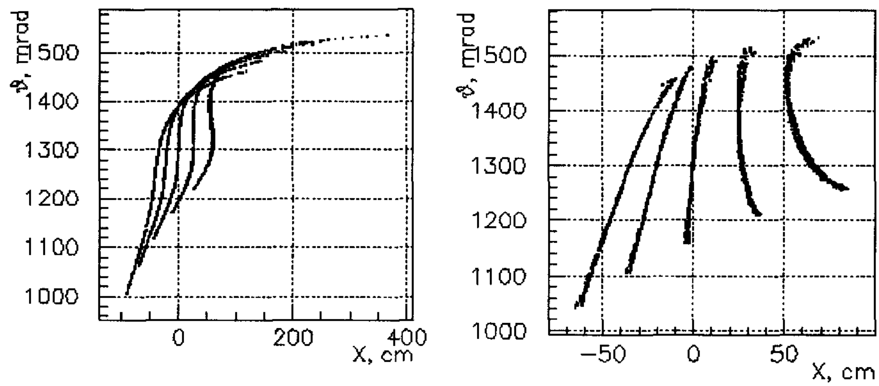

Figure 3. Image aberrations in the X-θ plane for the full momentum acceptance. Left : before correction of the shape of Q2, right : after modification.

the x-direction to introduce octupolar and dodecapolar field components as it is shown in Figure 3. None the less, reconstruction of trajectories is required to obtain good resolution. A new technique based on Newton method to invert the tranfert map to retroactively construct the trajectories of the particle is still in progress. Using this new technique it is important to reduce third and fifth order aberrations. Final definition of the higher orders to built in the Q-poles and in the dipole are still in progress.

3. FOCAL PLANE DETECTION SETTING

The large variety of experiments implies a very versatile detection system. Heavy ions from helium to transuranic nuclei and with a very broad energy range, from 0.1 to 20 MeV/nucleon, must be localized and identified. The detection system will need original technological developments to achieve this. Our present version, still subject to eventual modifications and improvements, is described below.

3.1 Position measurements

For light and fast ions, two drift chambers, very similar to the new SPEG multi-channel electronics chambers, will be used. A accuracy of 0.5 mm vertically, and of 0.2 mm horizontally for ion energies between 1 and 50 MeV/nucleon may be achieved. With two measurements at 10 cm distance, this corresponds to an angular resolution of 2 mrad. Two such detectors can be used, mostly set in front of and behind the focal plane. Main uncertainty in reconstruction will come from angular straggling in the entrance foils.

For lower energies and heavier ions, two detectors of the secondary emission electrons will do a double x-y and time measurement. The time resolution may be estimated to be 300ps. Position resolution of 1mm (FWHM) or better were obtained with such devices. Other possibilities are presently investigated and may turn out to be advantageous, such as the detection of the secondary electrons in a fast gas-detector.

Table 3. Detection set up of VAMOS

	Detection System	Measured quantities
Light / Fast Ions	Drifts Chambers Ionization Chamber Pastic	X - Y, θ -φ ΔE E - T
Medium heavy / Slow Ions	Electron emission foils Ionization Chamber Plastic	X - Y, θ -φ, T ΔE or E E
Very heavy Ions	Electron emission foils High resolution detector	X - Y, θ -φ, T E

3.2 Energy loss and energy signals

For high energies, > 5 MeV/nucleon, an ionization chamber operating in transmission mode could serve for dE measurements in combination with the E signal of a thick plastic detector. An E resolution of 1 to 2% can be considered realistic for energies above 5 MeV/nucleon. This resolution will be limited to 3-4% at energies the order of 0.1-0.2 MeV/nucleon. The dE resolution will be around 5%.

The E detector may be replaced by an Si-type segmented detector or by a segmented bolometric detector which allow simultaneous disintegration measurements.

3.3 Time signals

For mass identification, a time of flight measurement is necessary. Measurement of the arrival time at the focal plane will be given by μ-channel plate detectors or the plastic, with a time resolution of around 250 ps. The time of flight accuracy will thus be within around 350 ps. Time may be used too with respect to the cyclotron RF. In this case time resolution may be limited to about 2 ns (FWHM).

Depending on the energy and the mass of ions, two set-ups, combining all detectors described above, will be used at the exit of the spectrometer. The arrangement of the standard detection system is resumed in Table 3.

4. PARTNERSHIP

This project involves five european laboratories : GANIL (Fr), GSI (Ge), CCLRC Daresbury (UK) and the Universities of Liverpool and Surrey (UK). Outside of this contract, other institutions participate actively in its optimisation, development and construction, the IPN Orsay, the CENBG Bordeaux, the CEA/SPhN (Fr), the Universities of Giessen (Ge) and Manchester (UK).

5. CONCLUSION

The VAMOS spectrometer should be in operation before end of 2000. This new device provides an highly efficient and versatile tool to study reactions induced by the SPIRAL beams.