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Data Acquisition and Evaluation System
of the Cracow Nuclear Microprobe

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Abstract:

An overview of the Cracow nuclear microprobe together with its data acquisition and control system is presented. Magnetic deflection was applied for beam scanning, while detector signals acquisition is performed by the NIM / CAMAC modules under supervision of a Windows operating system running on a PC equipped with the GPIB controller card. Total spectra from every detector are accessible on-line during the measurement, while full information about detected energy and beam position is stored to a disk file in the list mode to allow off-line data analysis. System hardware and software setups together with software operations and data formats used for information storing are described.

An overview of the Cracow Nuclear Microprobe

The microprobe in Cracow is based on a HVEC KN-3000 type Van de Graaff accelerator with proton beam energy up to 3 MeV and energy stability of $\Delta E/E \approx 10^{-3}$. The focusing elements of the microprobe (two doublets of magnetic quadrupole lenses) were manufactured in the Micro Analytical Research Centre (MARC, Melbourne, Australia). The scanning system operates with the ferrite-cored magnetic coils of the Institute of Applied Physics (Sumy, Ukraine) design [1]. The focusing system (FS) of the operating microprobes (MP) with submicron resolution has usually the total length l of more than 5 m. Compact versions ($l < 4$ m) of an optimized FS based on a divided Russian quadruplet have a great promise for the next generation of MP [1]. The MP with such FS is economical in space, easy to align and less sensitive to mechanical vibrations than a long system. In particular, a large demand for such systems comes from biological laboratories, where a vertical position of the MP is preferable. Due to its unique construction [2,3], the Cracow microprobe is a very short one ($l = 230$ cm). The MP is installed in a new experimental hall located to the right angle from the accelerator compartment (Figure 1).

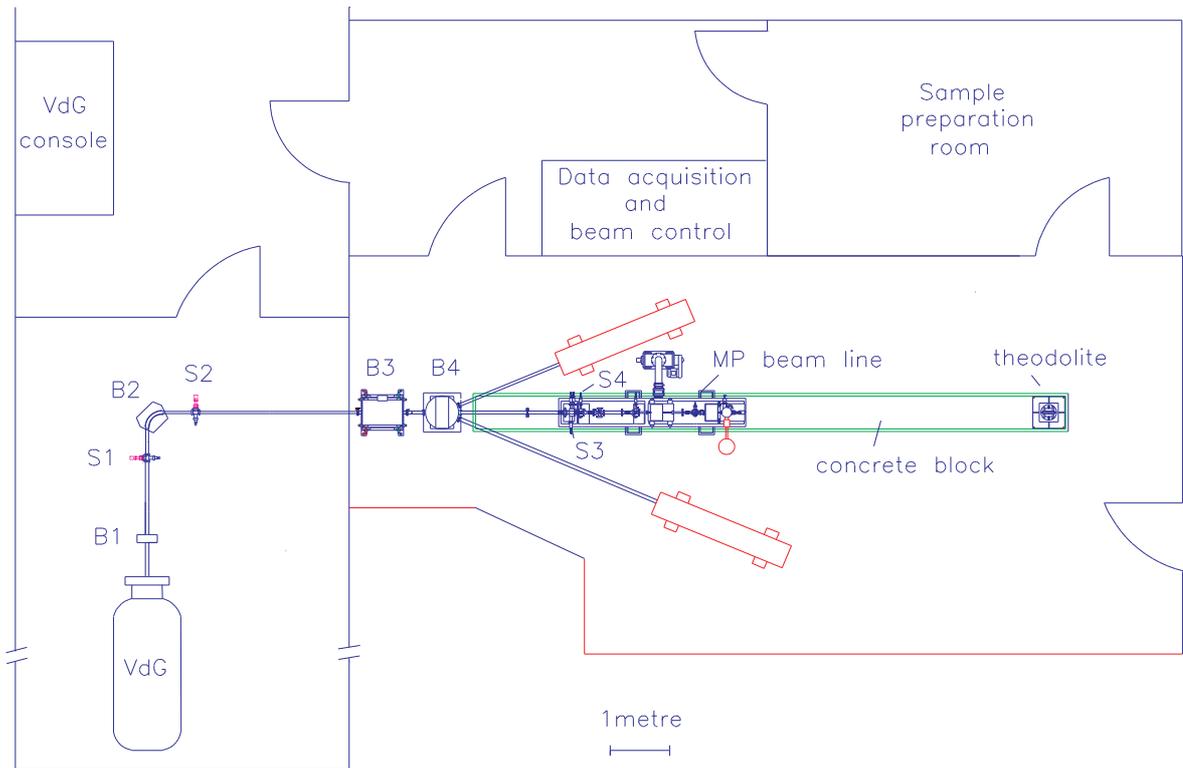


Figure 1. Layout of the Cracow MP unit. B1: dipole magnetic steerer; S1 and S2: entrance- and exit-slit boxes, respectively; B2: analyzing magnet; B3: quadrupole doublet; B4: switching magnet; S3: feedback slit; S4: object slit.

The ion beam from the accelerator is delivered to the object slit (S4) of the MP using a dipole magnetic steerer (B1), a 90° double-focusing analyzing magnet (B2) with a bending radius of 240 mm and with a doublet of magnetic quadrupole lenses (B3). The beam-optical transport system has been designed to minimize the degradation of the beam brightness due to chromatic and spherical aberrations. The magnetic field of analyzing magnet is stabilized using a power supply controlled with a Hall probe. A stability of the power supply of the magnet is of the order of 10^{-5} . The momentum spread of charged particles beam is stabilized by a feedback loop to the corona discharge current from the Van de Graaff accelerator terminal. The error signal for the feedback loop is taken from the beam current difference between left and right slit edges located prior to the object slit of the MP. A switching magnet (B4) is located before the MP enabling the use of the ion beam in standard experiments not requiring the micro-focusing optics.

The Institute is located close to a road with heavy car traffic, what requires careful precautions against mechanical vibrations of the MP system. The MP setup is mounted therefore on a heavy anti-vibrational concrete block 8 m long, put in a sand bath.

Figure 2 presents a schematic view of the MP beam line. A heavy table made of steel (1) is fastened to the concrete block. A position of the table is adjustable using precise screws (2). The elements of the MP line are mounted to the table using hard rubber attenuators. The ion beam line and the target chamber of the MP are pumped down with a 100 l/s ion pump (3) and a turbo-molecular pump (16) vibrationally decoupled from the setup using metal bellows and bunapren elastic sleeves (17). The turbo-molecular pump can be switched off during the most sensitive experiments.

The MP is connected with elastic bellows to the accelerator ion beam system and separated with a gate valve (4). Following the valve, a pair of tantalum slit edges (5) is mounted using linear feed-through micrometer screws. A difference of the beam current signals taken from the edges of the slits is used as an error signal for the feedback loop of energy stabilization.

A water-cooled circular slit (6) is mounted in the same vacuum box. The slit assures that only a central part of the beam can pass to the object slit (7). Following the experience of the MARC group, a commercial diaphragm made for a scanning electron microscope is used as an object slit. Several such diaphragms are mounted in a frame moved by a linear feed-through rod with a micrometer screw. In the same way an angular collimator (8) is constructed. Two doublets of the magnetic quadrupole lenses (9) are mounted on separate supports located after a box with the angular collimator. A two-dimensional ferrite-cored scanning system (10) is mounted between the last doublet of quadrupole lenses (9) and the target chamber (11). This new compact system (3.5 cm long only) for each scanning direction is composed of two coils wound on circular lobes of ferrite rings [1]. In the central part, where each pair of rings is glued together, a hole for the ion beam tube is drilled. The magnetic field at the ion beam position is sufficient for a scan area of $0.5 \times 0.5 \text{ mm}^2$ at the target for 2.5 MeV protons with working distance of 15 cm. The scanning system was developed and tested in IAP (Sumy, Ukraine). The deflecting field produced by the system shows a high degree of uniformity.

In several positions along the ion beam tube, there are boxes (12) enabling the beam diagnosis. Each box is equipped with a Faraday cup and a quartz or a BGO plate for the beam visualisation. In particular, the box (13) is located at the expected position of the cross-over of the beam between the doublets of quadrupole lenses. Each quartz plate for the beam spot visualisation is observed by a CCD camera (14). At the end of the MP beam line a target chamber (11) is mounted. The chamber is equipped with a rotatable x-y-z micromanipulator (18). At present, the detector system consists of a channeltron for secondary electrons detection, a surface-barrier detector for scattered ions and a Si(Li) detector (19) for PIXE measurements.

The x-y-z position of each element of the FS (the object slit, the angular collimator, the beam monitoring boxes, the doublets of the quadrupole lenses, the target chamber) as well as angles of its inclination with respect to the beam axis are adjustable by high precision screws (20). This construction enables a step-by-step procedure of fine adjustments of the MP elements with the proton beam and therefore it permits to find the best alignment with the maximum ion beam brightness.

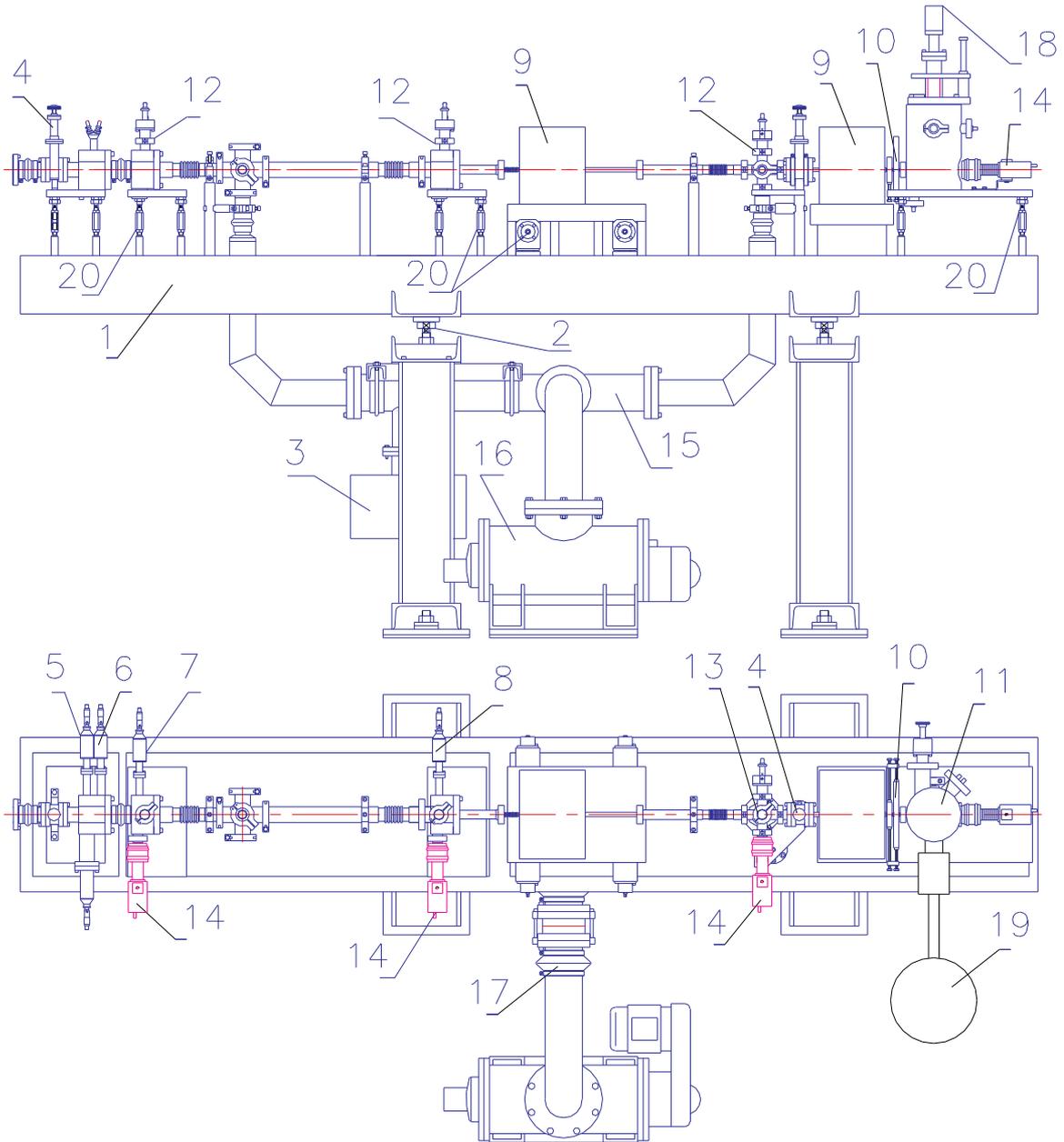


Figure 2. Schematic drawing of the microprobe beam line

The more detailed description of MP construction and parameters can be found in references [1,2,3].

Data acquisition system – hardware description

The hardware of CMB system consists of the three main parts:

- The magnetic beam deflection system based on fast power supplies (ES 030-10, 30 V, 10 A, 1.2 ms response, Delta Elektronika, Holland) controlled by a specialized GPIB module PSC-44M, also from Delta Elektronika.
- GPIB controlled CAMAC crate and a NIM crate containing at least the following modules:
ADC, constant fraction discriminator and gate generator, scaler, clock and GPIB CAMAC controller. In the present microprobe setup the data acquisition system consists of:
 - ADC 4418/V SILENA, 8 inputs, 4096 channels
 - CFD 584 ORTEC constant fraction discriminator,
 - GG 8010 ORTEC gate generator,
 - NIM-ECL-NIM translator model 82, CAEN,
 - CC-625 ELLEK GPIB crate controller.
 - clock (1MHz) and a quad scaler,
 - timing (863) and spectroscopy (572) ORTEC amplifiers, single channel analyzers and detector power supplies.
- Windows 98 PC microcomputer equipped with a GPIB card. The card is working as an interface between PC and CAMAC crate controller and between the PC and the beam deflection system.

Present setup allows to acquire the data simultaneously in multichannel and multiscaler modes with the detector pulse energy and/or number of counts data correlated with beam position information. The schematic diagram of electronic modules and their interconnections is shown in the following figures:

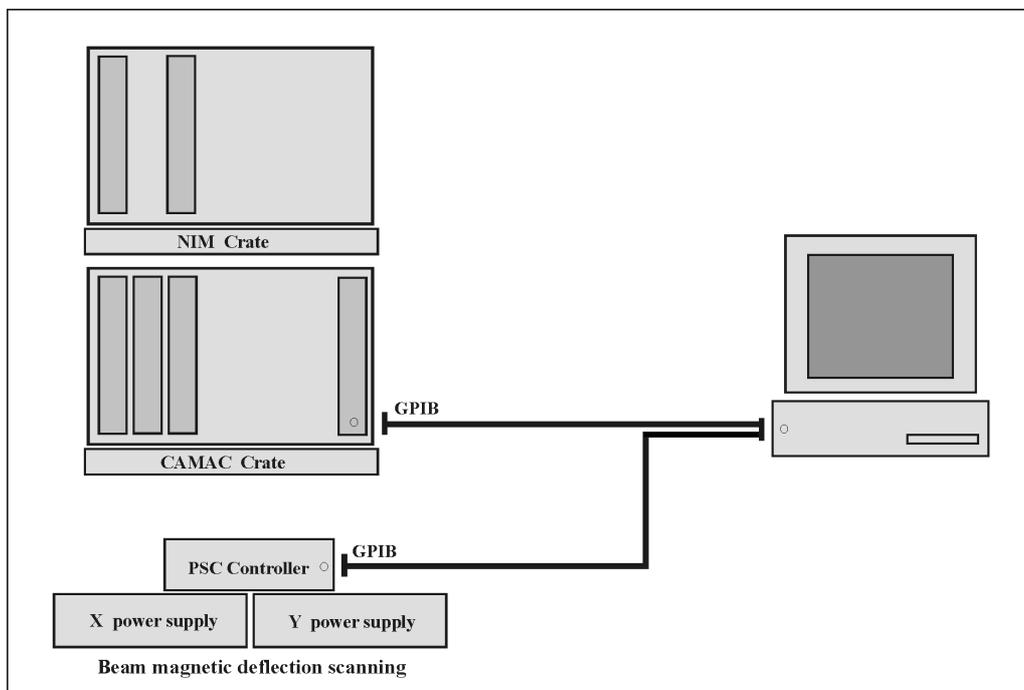


Figure 3a. Main modules of the CMB data acquisition system.

As it is described in the microprobe overview, beam scanning is performed by magnetic deflection. Because of the high inductivity of the deflecting coils, current changes cannot be very rapid. Therefore, in present setup the minimal reasonable time of single pixel irradiation is of about 10 ms. The useful (more or less linear) range of magnetic coils currents is limited to 2.5 A, what corresponds to a beam deflection of about 0.5 mm.

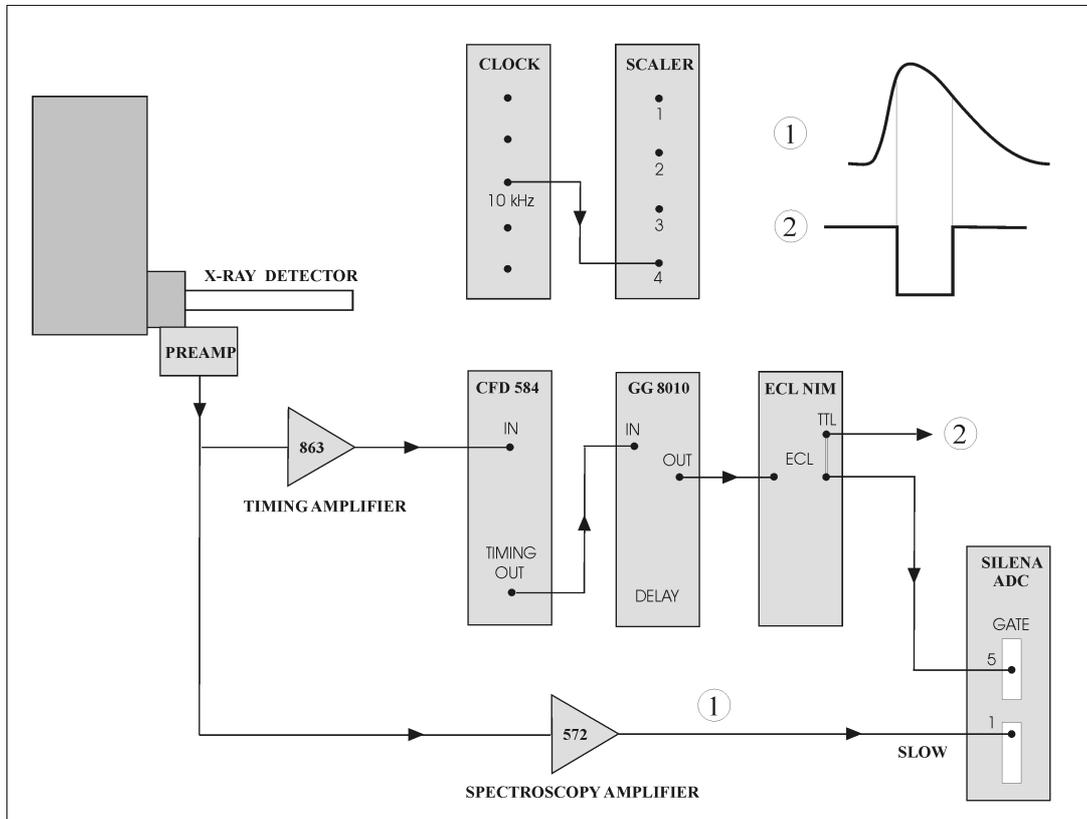


Figure 3b. An overview of signal connections.

General concept of the software

The CMB data acquisition system was developed as a hybrid of the two programming languages. The first one was the Tcl/Tk [4] VHL (very high-level) scripting language used for user interface construction and for offline analysis. The second part, performing time critical tasks was written in C/C++. Such approach allows for reasonable system performance in parallel to the rapid software development and modification. All the graphic windows shown in this paper and most of evaluation routines are written in Tcl/Tk. In the case of time consuming calculations (some display operations, data extraction etc.) the Tcl/Tk performance was enhanced using C language modules loaded as a DLL library into Tcl/Tk scripts. The DLL library was prepared with the use of SWIG wrapper and interface generator [5]. The separate executable responsible for CAMAC crate control, detectors and scalers readouts and beam scanning, was written using Microsoft Visual C/C++ Development Studio. Communication and data exchange between threads is assured by means of a shared memory. It should be pointed out that the CMB is an open system, to which a new hardware (detectors, CAMAC units) can be added easily with only a minor software updates.

Main CMB window

The principal window of the CMB data acquisition system is shown in the following figure:

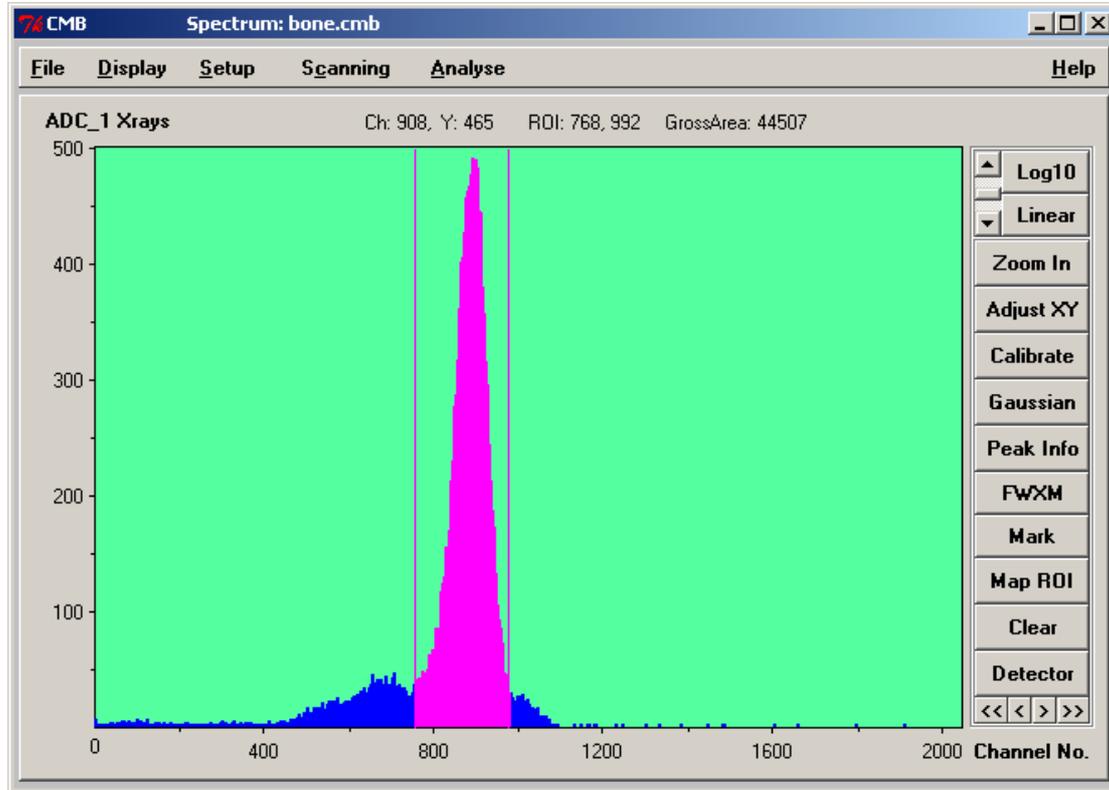


Figure 4. CMB main window.

Main window has a standard structure with a menu bar at its top, a rectangular window for spectrum display (with axes description) and several pushbuttons placed right to the spectrum rectangle. Their functions are more or less self-descriptive and are listed below:

- **Log10 / Lin** : Y axis display mode setting.
- **Zoom In** : after defining the region of interest (ROI) it is possible to limit the displayed spectrum only to ROI.
- **Adjust XY** : sets X and Y axis limits to values allowing for full spectrum display.
- **Calibrate** : allows for entering constant factors for energy spectrum calibration.
- **Gaussian** : Gaussian fit to a peak defined by ROI.
- **Peak Info** : Peak parameters – height, area, background, FWHM.
- **FWXM** : Full Width at X Maximum.
- **Map ROI** : provides visualization of surface distribution of particular element, defined by the registered x-ray energy. To specify energy of interest the user must first define the corresponding region of interest (ROI). This function usually deals with event files that must be accessible for the system. More information on maps is given in next chapter.
- **Clear** : removes experiment from memory and clears display window.

- **Detector** : allows for specification which ADC (or scaler input) should be displayed in the main window. This choice is enabled by launching a separate dialog window.

The top part of the CMB window displays some useful information about the displayed spectrum. Starting from the left, the currently displayed spectrum description is shown. Next, two numbers correspond to the current mouse position recalculated into channel number (or corresponding energy value) and Y position. Instead of the Y position of the mouse the current channel content may be displayed with the mouse left click. Finally, if the ROI is set, the *ROI limits* and the *ROI area* of spectrum are displayed. The *ROI limits* may be set (and reset) using the right mouse click (first and second clicks set the ROI, and the third one performs ROI reset).

CMB menu system

CMB main menu consists of the following items: File, Display, Setup, Scanning, Analyse, and Help. The following description covers all functions accessible for the user from the menu.

♣ Menu **File** enables standard manipulation on data files like loading or saving them and contains the following options:

- Open Experiment
- Merge Experiments
- Load Spectrum / Map
- Load Spectrum / New Window
- Save Experiment As...
- Save Spectrum / Map As...
- Exit

The above options are mostly self-descriptive. “Merge Experiments” item is provided to allow to combine two separate experiments into a single one. Of course, all vital experiment conditions (like pixels number or beam shift) must be the same for the combined spectra.

As it is reflected in the **File** structure, the data files are divided into three main categories:

A. Experiment contains full information about the performed measurement: total ADC spectra¹ registered by all detectors and the values of readouts of all counters used. All events are stored in disk files providing off-line access to energy and beam position for every registered detector pulse. This information is contained in three files:

- One ASCII file containing a header describing the experiment conditions followed by total spectra of all active detectors and digital counters (scalers). The default extension of this file is “.cme”, but in general the name and extension may be set freely.
- Two binary event files, one for ADC events and one for scalers readouts, containing the same ASCII header as the ASCII file. The names of binary files are set by the CMB system and are constructed as follows:

¹ The term “total spectrum” is used to denote raw ADC spectra where detector pulses are not associated with the beam position information.

- ADC events: **ea_hh_mm.cmb**, where “**ea**” is a fixed prefix, “**.cmb**” a fixed extension, “**hh**” and “**mm**” denote the time of starting the measurement. Underscores are used as separators.
- Scalers readouts: **eq_hh_mm.cmb**, where “**eq**” is also a fixed prefix and the rest of the file name is constructed like in the case of ADC.

The structure of binary data record in an event file is as follows:

ADC events:	Scaler readouts:
BYTE x position	BYTE x position
BYTE y position	BYTE x position
WORD channel number	DWORD readout value
BYTE detector number	BYTE scaler number

Because of a large size of event files and the redundant structure the experiment files are always compressed into a single archive during save operation. The archive name is the same as the experiment file name plus the extension “**.rar**”.

B. Spectrum file contains a single total spectrum associated with a particular detector without any positional information. Standard header describing the experiment conditions is added at the file beginning. Such file contains only one spectrum and is provided mainly for easy exporting/importing ASCII data to and from external programs.

C. Map file contains information limited to particular detector and energy range correlated with the beam position. Maps allow for PIXE / PIGE or RBS studies of surface distribution of elements. This data representation format may be constructed with the combined use of event files and total ADC spectrum (the most straight-forward option) or by analyze of QS counters spectra. Map is displayed using a color representation for number of counts in every pixel² corresponding to the beam position.

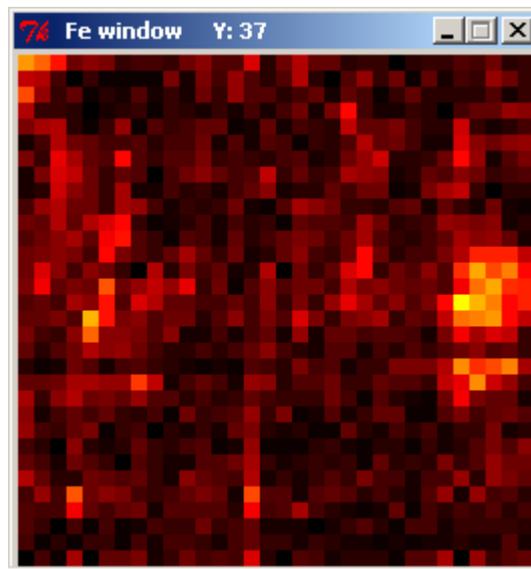


Figure 5. An example of the elemental map window.

² “Pixel” is used to here (and later) to represent the beam spot on a target and **not** the single pixel displayed on a screen. A beam spot “pixel” of a map is represented by a square area of NxN screen pixels where N depends on screen resolution, scan size and beam position step.

A map is “clickable”, i.e. pressing left mouse button over a map area displays the number of counts corresponding to the mouse pointer position. The color scale of the map may be either linear or logarithmic (see menu Display).

♣ Menu **Display**

This popup menu allows for change of the display mode, screen details and screen colors. The acquired spectra may be displayed as a scatter graph, bars or a line. The color of most of the display regions may be adjusted according to user’s preferences. It is also possible to section the Y axis using the horizontal grid. Finally, the user may decide whether linear or logarithmic color scale should be used for maps.

♣ Menu **Setup**

Main task of this item is to open a window providing the user input for defining the measurement conditions used for microprobe experiment.

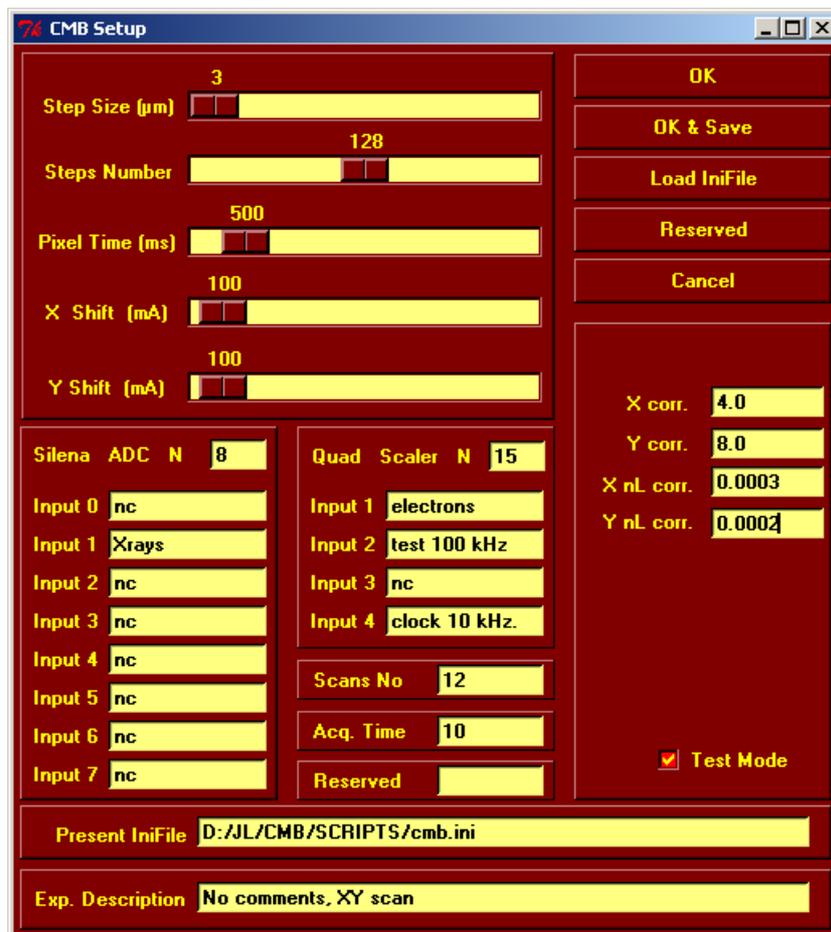


Figure 6. CMB setup window.

The adjustable parameters are as follows:

- **Step size** determines the beam position update single step in a range from 1 to 100 microns.
- **Steps number** × **Step size** product determines the scan area. The maximum value of **Steps number** is 256. At present, due to the characteristics of the scanning coils, scan area is limited to about $500\ \mu\text{m} \times 500\ \mu\text{m}$.
- **Pixel time** represents the time when the beam is positioned at a particular spot on a sample and detector pulses are acquired. At present, this time corresponds to beam position update rate. In future, beam will be switched off during the position update and pixel time will correspond only to a stable position of the beam on a target. Pixel time may be adjusted between 1 ms and 5 sec.
- **X Shift** and **Y Shift** allow for horizontal and vertical adjustment of the beam position on target.

The lower part of Setup window describes the details of the acquisition system:

- **ADC N** and **Quad Scaler N** edit boxes correspond to position of these modules in a CAMAC crate.

Not connected ADC and QS inputs should contain “**nc**” in their edit boxes.

Any other character string in an Input edit box means that this input is used and provides a description of detector signals connected to this input.

Input 4 of the quad scaler is connected to a 10 kHz clock output (cf. Figure 3b). This provides an independent 100 μs resolution timer for the whole system.

Edit boxes of X and Y corrections (linear and nonlinear) correspond to coefficients used to calibrate and linearize the scanning system. Beam scanning is accomplished by changing the magnetic field which deflects the beam in X and Y directions. This is accomplished by controlling the current delivered to two perpendicular magnetic coil pairs. In example, at present coils parameters and the low X current (less than 0.5 A), the current change of 5 mA causes beam deflection of about 1 micron.

The remaining edit boxes are self-descriptive. The difference between **OK** and **OK & Save** buttons is that **OK** stores the actual parameters for the current session only, while **OK & Save** writes them to initialization file. One should mention also the **Test Mode** checkbox which is provided for allowing a convenient way of the system testing. When checked, it disables all system hardware calls.

It is not practical to use a **Setup** window to change scanning parameters during normal work of the system. While the coefficients like linear / nonlinear corrections or CAMAC blocks positions will not change frequently, the other parameters like scan size or pixel time must sometimes be adjusted many times during the measuring session. Therefore a separate panel window is provided, launched automatically during program start (or accessible through menu item **Scanning / Control Center**).

♣ **Control Center** window is shown on the following figure:

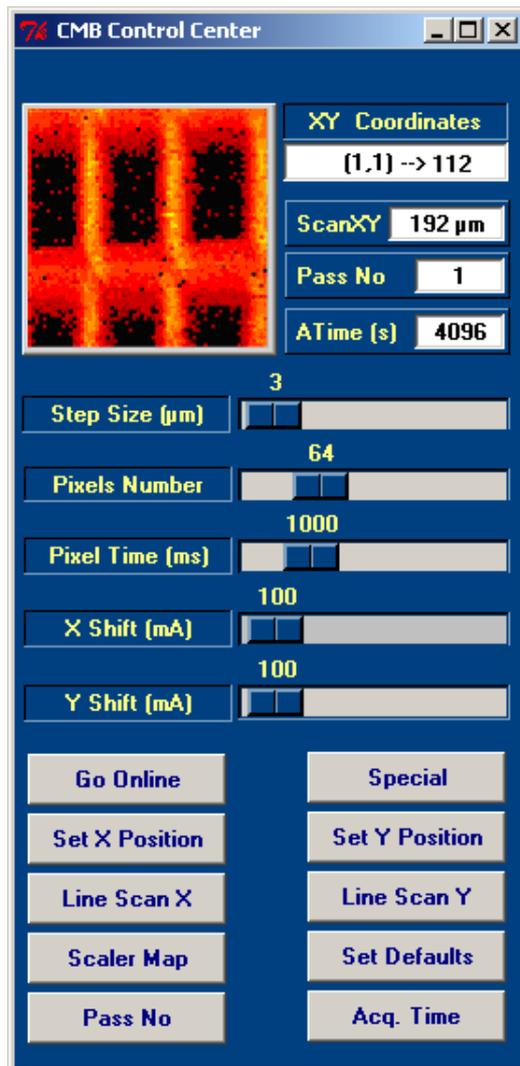


Figure 7. Scanning parameters window.

In the top left part of the window a map is displayed which main task is to show a momentary position of a beam during scanning and (optionally) a secondary electrons image of the scanned area. In the Figure 7 an example secondary electrons image of calibration grid is displayed. The example image shows severe nonlinearity of the beam deflecting system and was used as a base of scanning system linearization. Map is “clickable” – the topmost edit box (XY Coordinates) displays the XY position and Z readout (counts number) corresponding to a position of mouse click.

Small edit boxes (read only) located to the right of the map show the actual scan size, calculated time of scanning corresponding to present settings and the required number of beam passes through the scanned area.

Horizontal sliders allow for easy adjustment of the five main scanning parameters.

The lower part of the Control Center window is occupied by ten buttons. Their functions are as follows:

- **Go Online** – starts a time-critical application **cmb_w32.exe** (written in C/C++ language) responsible for beam scanning, detectors data acquisition and online display. During **cmb_w32**

execution a new window is displayed (similar to main CMB window, but with much faster update).

- **Special** – starts the same **cmb_w32.exe** application but in specialized scanning mode (foreseen for beam lithography).

- **Set X/Y Position** – set horizontal/vertical shift of the beam position on target. The function is performed immediately after pressing the button. This function is not needed for normal scanning as beam shifts (determined by X/Y Shift sliders) are applied automatically before scan starts.

- **Line Scan X/Y** – operation similar to normal scanning mode (**Go Online**), but in this case the scan is performed along the single horizontal or vertical line only.

- **Scaler Map** – displays the map obtained by correlating scaler readouts (usually the registered secondary electrons number) with the position of the beam on target. The user decides which scaler should be displayed.

- **Set Defaults** – re-reads the default scan parameters from the initialization file.
- **Pass No** – determines number of beam passes over the scanned surface needed for completing the measurement. After setting the **Pass No** the acquisition time of experiment is calculated and displayed.
- **Acq. Time** – sets the maximum acquisition time for a measurement. This value does not affect other scan settings with the exclusion of **Pass No** which is automatically adjusted if needed.

Minimal **Acq. Time** is determined by the product of **Pixel Time** \times **Pixels** \times **Pixels**.

♣ Menu **Analyze**

This menu position gives access to the following options:

- **Experimental Data** displays all of the scanning parameters of the experiment displayed currently in the main window. This includes e.g. date and time of experiment, all scanning parameters and corrections, detectors and scalers which were active during the measurement and the names of event files.
- **Normalize** allows for easy spectrum normalization by simple channel contents multiplication.
- **Elemental Map** provides visualization of surface distribution of particular element, defined by the registered x-ray energy. To specify energy of interest the user must first define the corresponding region of interest (ROI).
- **QS** \rightarrow **Line** and **Map** \rightarrow **Line** options are useful particularly for the test phase of microbeam development and provide one-dimensional projection of the scaler or ROI map.
- **Background subtraction** allows for correction of the displayed map by removing the calculated background.

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