Exposure of an ECC to ^{12}C beam at NIRS (Chiba) in October 2004.

Giovanni De Lellis

The aim of the exposure is to measure the fragmentation induced by 400 MeV/u Carbon beam used in hadron-therapy. Given the path length of the Carbon beam at this kinetic energy, an ECC chamber made of 219 OPERA-like ES and 219 1mm thick lexan sheets was assembled. The lexan sheet was cut to the same size of the OPERA films: 125 x 100 mm^2. The thickness of lexan sheet was measured to be 1.064 ± 0.004mm and its density 1.15 g/cm^3. Therefore its behavior is well representative of the water at a first approximation.

We used a uniform structure of the chamber, keeping the same granularity. 73 units were made. Each unit was made of 1 lexan, 1 ES, 1 lexan, 1 ES to be refreshed at 30 degrees, 1 lexan and 1ES to be refreshed at 38 degrees. The total length of the 73 units was about 299 mm. The use of different refreshing (after exposure) rates and no refreshing films was adopted to modify and expand the sensitivity range of the emulsions in order to be sensitive to heavy ion ionization.

The assembling of the chamber was made so that the upstream part starts with lexan, for mechanical reasons. Fig. 1 shows the assembling procedure and the convention adopted for the emulsion sheet orientation on the support. The piling-up of the chamber was done inside two suitably-made thick papers: they were used to wrap the chamber soon after the piling-up and protect the corners. A vacuum packing was done with light-tight laminated film. Emulsions used come from the following batch (September 2003): 006-01 2003/9 C07-02.

The labeling of the ES started from the most-upstream ES (number 1). The label is printed in the reference corner. Fig. 2 shows the top view of the ES as put on the fiducial mark grid printing machine. The fiducial mark inter-distance is 1 cm. Notice that both labeling and grid printing was done soon after the exposure.

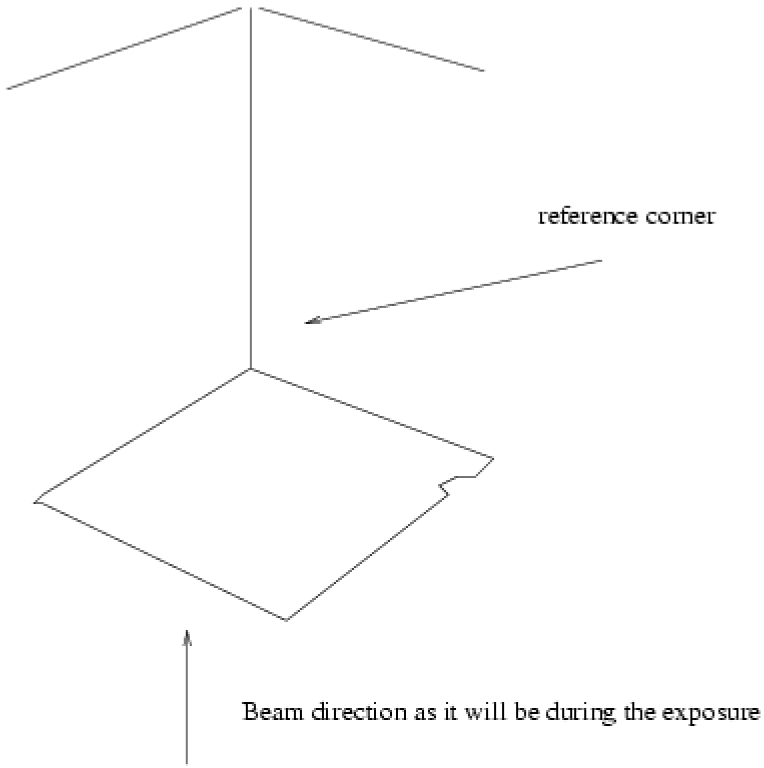

Fig. 1: Schematic view of the assembling procedure.

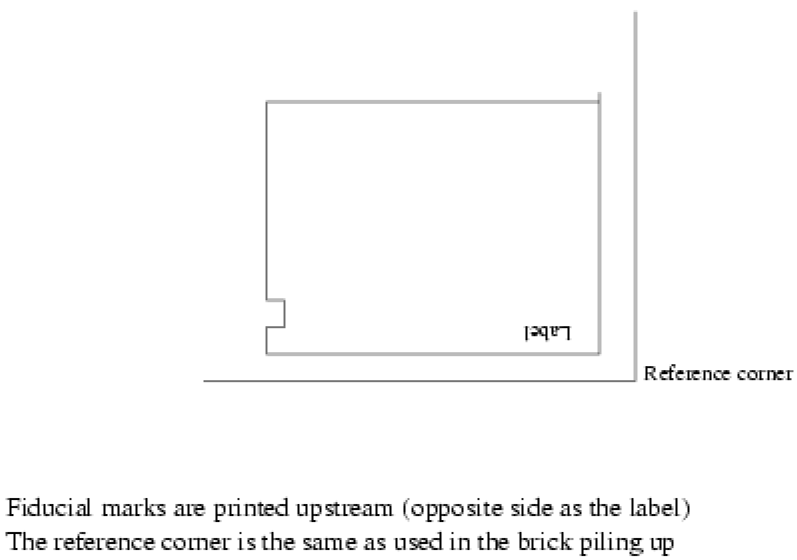

Fig. 2: Schematic (top) view of the fiducal mark printing.

In Fig. 3, it is shown the experimental hall where the exposure was performed while in Fig. 4 the experimental set-up used is shown. Notice that Fig. 3 shows the last 6 to 7m of the layout sketched in Fig. 4. In order to monitor the beam intensity, a scintillator counter is used. There is no need for coincidence, since the signal shows a peak of about 2V while the

Fig. 3: The experimental hall.

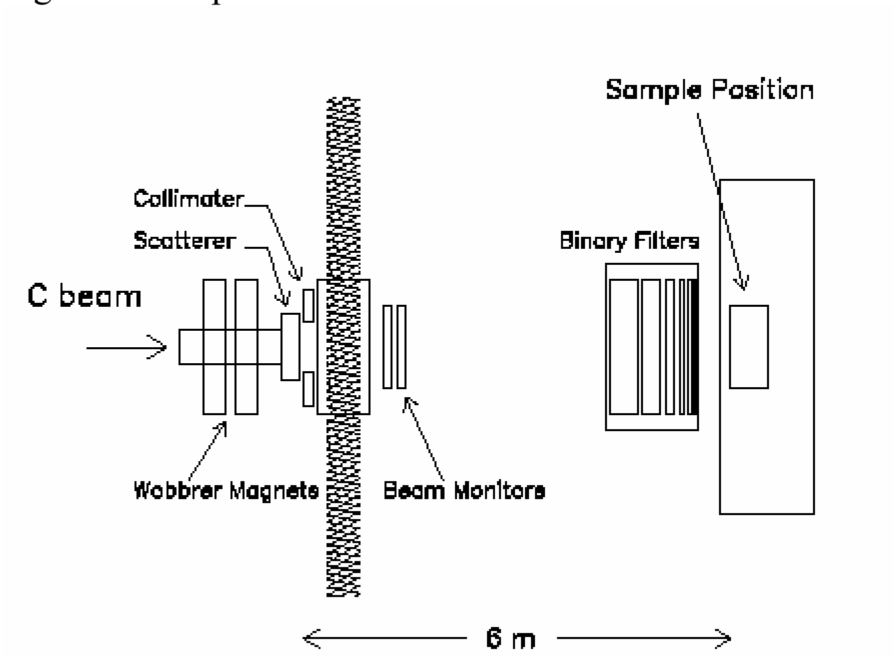

Fig. 4: Schematic view of the most down-stream beam pipe and experimental set-up. The sample position corresponds to the target position.

background is about 50 mV. The scintillator has an effective surface of 1cm^2 and a thickness of 1mm.

The period of the accelerator cycle is 3.3 s. The beam profile is shown in Fig. 5. A very good uniformity (better than 10% level) was guaranteed on a 10 x 10 cm^2 surface. A Carbon beam rate of 100 particles/cm^2 was achieved. The exposure rate was 2000 particles/cm^2 /angle where three angles were used: -120, 0, 120 mrad. The angular spread of the beam is about 16 mrad. Nevertheless the expected accuracy of the exposure angles quoted above was not better than a few tens of mrad due to the mechanical accuracy of the chamber positioning.

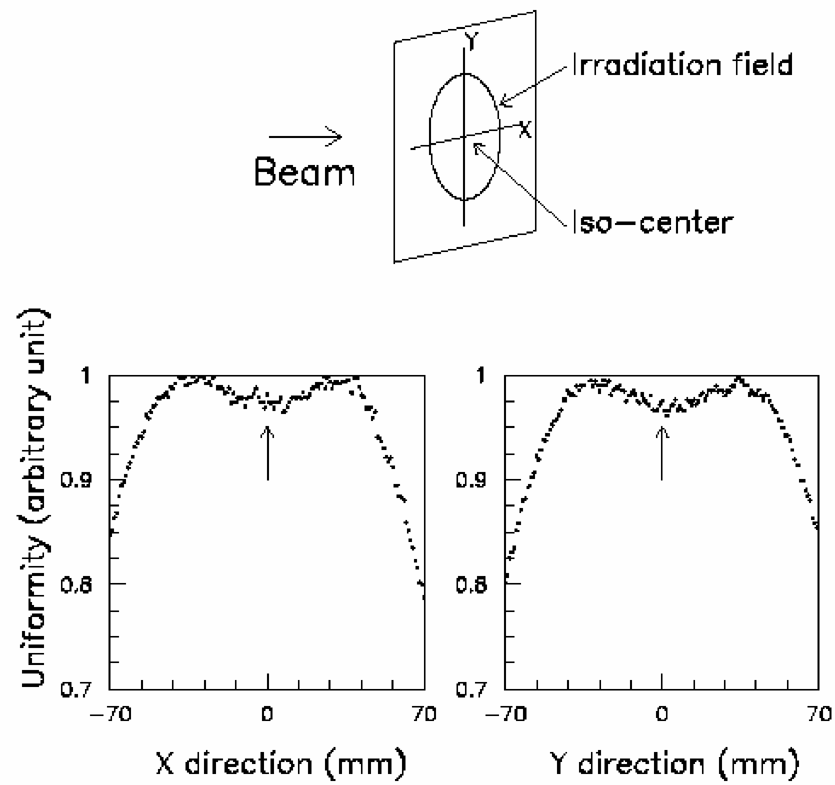

Fig. 5: Beam profile measured at HIMAC.

Figure 6 shows the range of the beam in water equivalent thickness, as measured on the site. The Bragg peak is at about 26 cm indicating an effective kinetic energy of about 350 MeV per nucleon. The reduction was mainly due the air target upstream of the target. Figure 7 shows the position of the chamber on the sample position. The horizontal tilting of the chamber was achieved by a simple ruler and hence the very rough positioning. Precise tilting is not needed though. In the following section, we report a detailed schedule and description of all operations.

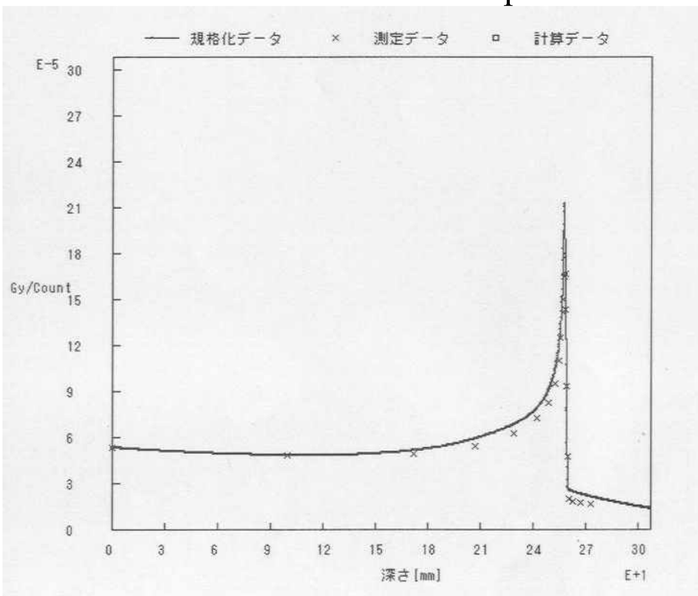

Figure 6: Carbon range in water equivalent thickness, measured on the site.

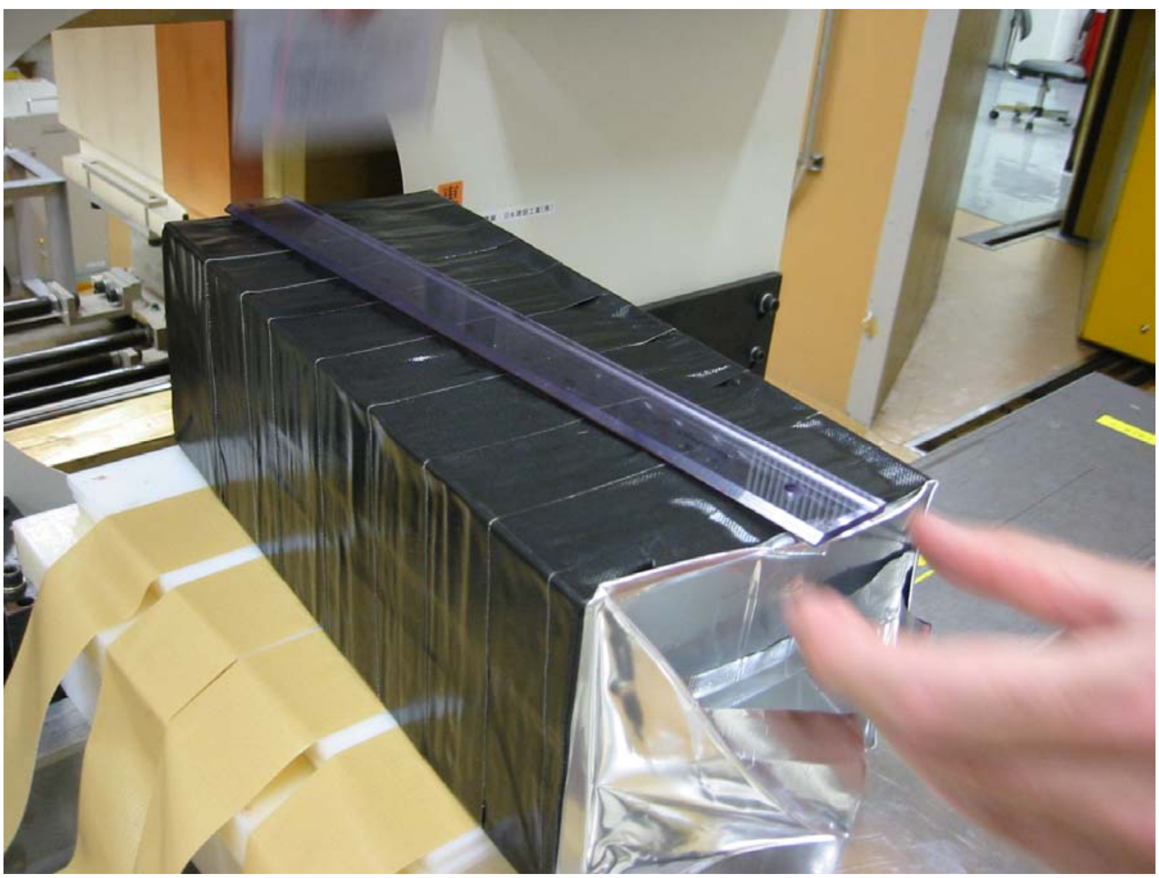

Fig. 7: Chamber on the target position. A simple ruler is used to tilt horizontally the brick with respect to the beam direction. The beam center is checked by a laser signal.

Schedule and description of all operations.

October 3rd , 8:30 pm: compatibility test for 1 emulsion vacuum packed with one lexan sheet and 1 emulsion vacuum packed as reference. Both packages were put into a 30 degree chamber for acceleration test. Every 5 degrees there is roughly a factor of 3 in the chemical reaction speed (Arrhenius). We keep it for one day in the acceleration chamber which corresponds to about 9 days for safety, although the contact between emulsions and plastic will be for about 2 days only.

October 4th at 8:30 pm: taken out to cool down

October 5th: emulsion films cut into two parts and one half packed to be exposed horizontally to the electron beam (100 MeV) for sensitivity measurements. First trial of brick assembling with the existing facility. The crucial point is the plate to plate alignment. A reference corner is needed for such a "long" pile. Built a new one with the required size in the mechanical workshop, see Figure 8.

October 6th: exposure to the electron beam

October 7th: 2 test emulsions developed

October 8th: sensitivity and fog checked: 35 grains/100 μm and 3/1000 μm^3. A prototype to be used as support for emulsions in the refreshing chamber was assembled.

October 9th: support for emulsion refreshing tested in the refreshing chamber. Good performance. Emulsions to be aligned along the air flow direction.

October 11th: vacuum packing of the emulsion chamber as shown in Fig. 9.

October 12th: exposure from 10pm till 13th 6am

October 13th: unpacking of the chamber and labeling of all 219 ES printed fiducial marks for 73 ES to be refreshed at 38 degrees)

October 14th: refreshing of 73 ES (3 days and half, 38 degrees and 98%) started at 4:45 a.m. with a ramp-up of 1 hour

Figure 8: support for the piling-up of the chamber.

October 14th: printed fiducial marks for 73 ES (without refreshing) to be developed

October 15th: development of 59 ES started at 1:00 am (dev. T = 19.6 C) and of 14 ES started at 3:20 am (dev. T = 19.2 and adjusted to T = 19.7): the acceptable range for 25 minute development is 19.6-20.4. Afterwards, the two batches were kept into the glycerin bath for 36' (59 ES) and 20' (14 ES) respectively.

October 16th: fiducial mark printing for 73 ES (to be refreshed at 30 degrees) at 2 am

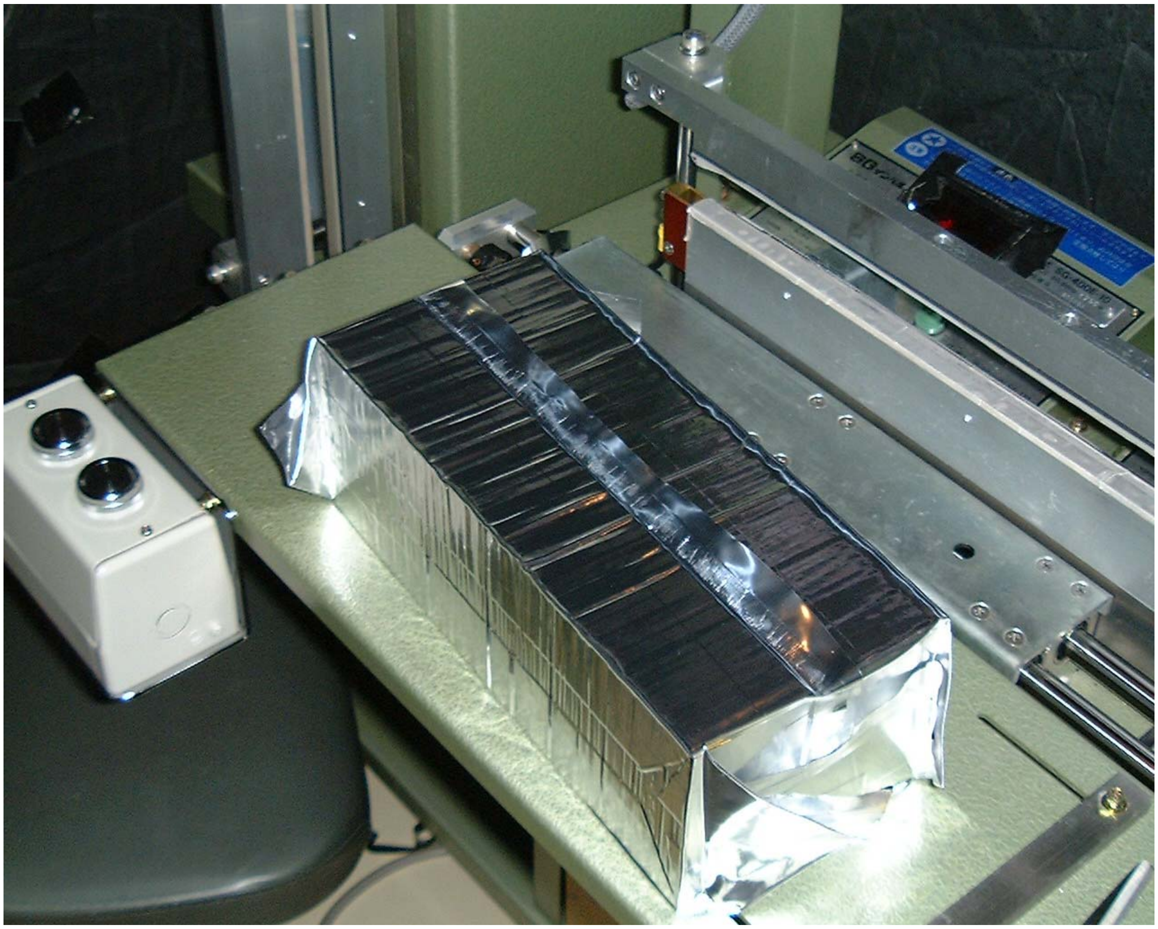

Fig. 9: Chamber after its assembling and vacuum packing.

October 17th: removal of 73 ES from the refreshing chamber at 11:30 pm

October 18th: 0:30 am insertion of 73 ES (3 days, 30 degrees and 98%)

October 18th: development of 60 ES (38 C) at 3:35 pm (dev. T= 20.3 C) and of 13 ES at 6:30 pm (dev. T = 20.0 C). Afterwards, the two batches were put into the glycerin bath for 20' (60 ES) and 20' (13 ES) respectively.

October 21st: removal of 73 ES from the refreshing chamber at 2:30 a.m.

October 21st: development of 58 ES (30 C) at 5:00 pm (dev. T = 19.0 adjusted to 19.9 C) and of 15 ES at 7:00 pm (dev. T = 19.7 C). Afterwards, the two batches were put into the glycerin bath for 20' (58 ES) and 20' (15 ES) respectively.

October 22nd: packing of all films after drying

Notice that: labeling of the first 4 ES might not be reliable. During the refreshing, ES 74 and 71 got in touch in the middle part and the same happened for ES 146-149.

We gratefully acknowledge the help and support provided by Nagoya University group and in particular by T. Toshito, A. Ariga and N. Naganawa. A special thank goes to Y. Furusawa and N. Yasuda of the NIRS institute for their warm welcome and collaboration during the exposure.