

Exposure of an ECC to the 400 MeV/u Carbon beam at NIRS in October 2005

G. De Lellis, C. Pistillo

The purpose of this exposure is to measure the charge of the Carbon interaction daughters and to attempt the different isotope identification, measuring the mass by means of the momentum measurement. The charge is measured by using emulsions with different refreshing degrees after the exposure. The momentum is measured through the detection of the multiple Coulomb scattering. The sensitivity of this method increases with the amount of material used, lead plates in this case. Nevertheless, the increased number of lead plates would cause the ion to interact and then make the momentum measurement impossible. A compromise has to be made. We decided to study the isotope identification only for the lightest isotopes, i.e. the isotopes of Hydrogen and Helium ions. It has to be stressed that these isotopes are the most abundant in the fragmentation.

Design of the first chamber

The structure of the first chamber is divided into 3 parts: target, charge spectrometer and momentum spectrometer.

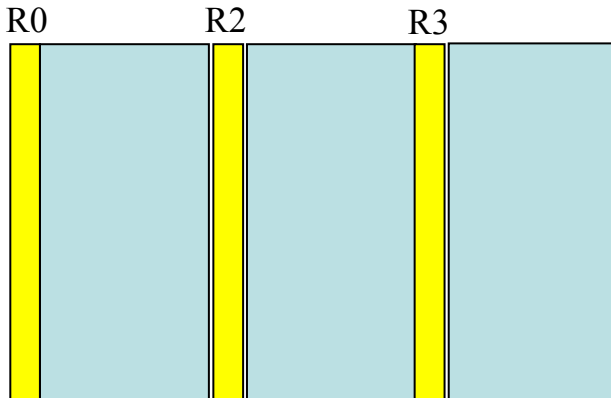


Figure 1: one of the 7 units of the target section

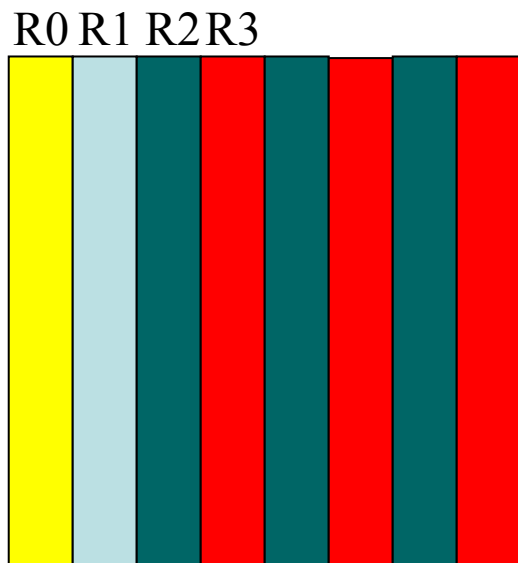


Figure 2: one of the 5 units of the charge spectrometer section

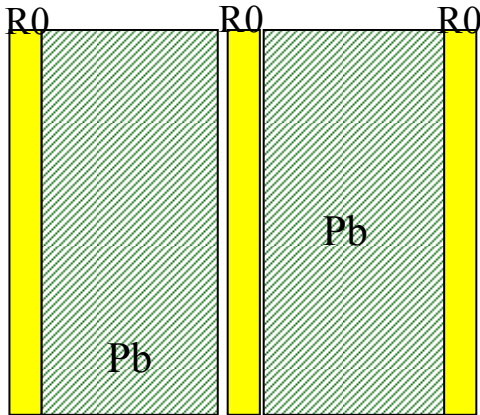


Figure 3: Schema of the momentum spectrometer section: 20 Pb plates and 21 ES (R0)

The target section is made of 7 units. Each unit is made of 3 Lexan sheets (1 mm thick) interleaved with R0, R2 and R3 Emulsions Sheets (ES) as sketched in Fig. 1. The convention adopted for the naming of the ES is listed in Tab. 1. Such a target will make about 10% of the Carbon ions to interact. 21 ES are used in the target. This section is followed downstream by the so-called charge spectrometer section. It consists of 5 units as shown in Fig. 2. The role of R0 and R1 is to provide the identification of Hydrogen and Helium together with R2. The sequence of R2 and R3 is designed to identify particles with Z from 3 to 6. This section is only made of 40 emulsions. The third and last part is made of a sequence of R0 type emulsions and 1 mm thick lead plates (calcium lead). 21 ES and 20 lead plates constitute this part. In total there are 82 ES: 33 R0, 5 R1, 22 R2, 22 R3. There are also 21 Lexan sheets and 20 lead plates: the thickness of both materials is 1mm for each plate.

ES type	Refreshing Temperature
R0	30 (before exposure)
R1	30
R2	38
R3	42

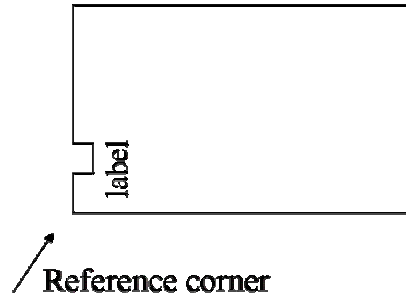
Tab. 1: conventions adopted in the naming of the ES. The refresh is applied after exposure when not specified.

Design of the second chamber

This chamber is designed to prove the feasibility of the Hydrogen and Helium isotope discrimination. The identification of charges from 3 to 6 is not required. Emulsions from R3 type will not be used in this case. Three sections are foreseen in this case as well. The spectrometer section is made of a sequence of 5 units (R0-R1-R2 each): 15 emulsion films only. The target has the same structure as shown in Fig.1 except for the fact that R0, R1 and R2 ES are used: 21 ES in total and 21 Lexan sheets. The momentum measurement sector is exactly the same as for the first chamber: 21 ES (R0 type) and 20 lead plates. In total we have 57 emulsions: 33 R0, 12 R1 and 12 R2.

Emulsion conditions

Emulsion of the R0 type were taken from the batch of already refreshed films in Tono mine, due to the large background accumulated. The other emulsions were taken from 3 non refreshed packs (29 ES each), given the fact that they will be refreshed after the exposure.



Fiducial marks are printed on the opposite side of the label (downstream).
The reference corner used for the gridding is the same as for the piling up.

Figure 4: schematic view of the fiducial mark printing

Material description

The lexan sheet was cut to the same size of the OPERA films: 125 x 100 mm². The thickness of lexan sheet was measured to be 1.054 ± 0.001mm and its density 1.15 g/cm³. Therefore its behavior is well representative of the water at a first approximation. The assembling of the two chambers was made so that the upstream part starts with the target section then the charge measurement section while the momentum measurement part is the most downstream one. 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 batches as reported in tab. 2.

Emulsion type	Lot number	production year/month	Roll & Box No.	Pack No. or code
non refreshed	011-02	2004-6	C07-01	C06-067--C06-069
26 refreshed	019-04	2004-12	F11-02	271004-02B12
14 refreshed	019-03	2004-12	C09-01	271004-02C12

Tab.2 : details of the emulsions used

The labeling of the ES started from the most-upstream ES (number 1). ES from the charge chamber are labeled with C1 to C82 while the ones in the momentum chamber are labeled with M1 to M57. The label is printed in the reference corner. Fig. 4 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 and before the refreshing. After development it turned out that the first (most upstream) 26 R0 emulsions used in the first (charge) chamber were not refreshed before the exposure.

In order to monitor the beam intensity, a scintillator counter is used with an effective surface of 1cm^2 and a thickness of 1mm . The period of the accelerator cycle is 3.3 s . A very good uniformity (better than 5%) was achieved on a $10 \times 10\text{ cm}^2$ surface. A Carbon beam rate of about $200\text{ particles/cm}^2$ was obtained. The exposure rate was $2200\text{ particles/cm}^2/\text{angle}$ where three angles were used: $-150, 0, 150\text{ mrad}$. 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. In fig. 5 it is shown the chamber position before the exposure. In fig. 6, the energy deposition rate of the carbon is measured by the gas chambers along the beam-line.



Fig. 5: Chamber positioning before the exposure.

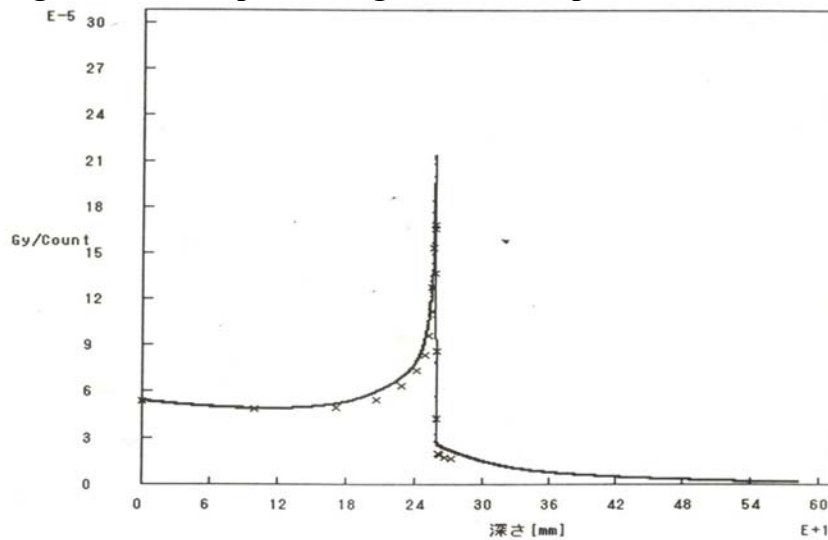


Fig. 6: Carbon range in water equivalent thickness as measured on the site.

Third sample

A third sample made of 14 emulsion sheets has been exposed. It was used to optimize the refreshing time and development conditions. 14 ES were put downstream of 25 ES and 9 mm lexan (see fig. 7) in order to get Carbon and its fragments. They will be treated at 42 degrees with different refreshing and developer time to optimize them to the carbon, boron and beryllium. A view of the sample on the beam is given in Fig. 8. The beam density was 20000 particles/cm² in the vertical exposure and 60000/cm² in the horizontal one (which corresponds to about 3 tracks/layer in 100 x 100 μm²).

25 ES 9 lexan 14 ES

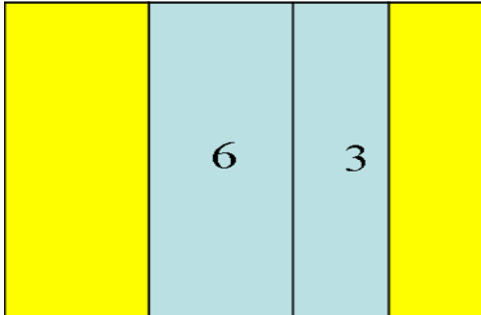


Fig. 7: schematic view of the third sample



Fig. 8: third sample on the beam line

Schedule of operations

A detailed schedule of all operations is reported in this section.

October 3rd, development of 3 peaces of sheets exposed to Carbon beam and refreshed at 45 degrees for 3 and 6 days respectively.

In order to improve the performances of the charge discrimination especially for charges 4 to 6, the idea is to use higher temperature in the refreshing procedure. 45 Celsius

degrees would accomplish this task, but the increase of fog (random grains per unit volume) would make the background level intolerable by the analysis of fast automatic microscopes. One attempt to reduce the fog, is to reduce the developing time of the developer solution. This is typically set to 25 minutes to get a good sensitivity to minimum ionizing particles. We made 5 test samples with developing time ranging from 5 to 25 minutes and compare them. This is reported in the table 1 where the fog is expressed in the unit of number of grains per 1000 μm^3 .

October 5th, measurement of the fog density

	Refreshing days	3	6
Developing time (')	Fog		
5		1.5±0.3	6.7±0.9
10		2.8±0.5	7.0±0.9
15		8.0±0.8	11.5±0.9
20		11.0±0.9	16.4±1.1
25		19.3±1.2	21.4±1.3

Tab. 3 Fog density measurement

October 6th, start the refreshing of 22 horizontally exposed sheets for 3 and 6 days.

The shorter the developer time, the lower the sensitivity. Therefore this may erase the Beryllium and Boron tracks. In order to test the sensitivity decrease, we decided to start the refreshing in the above conditions for sheets exposed horizontally to Carbon beam one month before. Horizontal exposure allow to count by eye the number of grains per unit length.

October 7th, developed 6 ES with developer times of 5 to 15 minutes.

In order to see the response of the automatic microscope (UTS) to the reduced developing time, we decided to develop the other parts of the sheets non used for fog measurements considering only 5, 10 and 15 minutes of developing time. Longer developer times are excluded due to the large fog contribution. Tab. 3 summarizes the different developing conditions of the sheets.

				Refreshing days
Developing time(')	5	10	15	
Plate number	35	32	29	3
"	26	23	20	6

Tab. 4: Different developing time for the sheets considered.

October 9th, 11 ES taken out from the refreshing chamber and packed. The refreshing chamber driven back to 45 degrees. These 11 films are developed with 5, 10 and 15 minutes of developer solution

October 10th, the analysis at the automatic microscope of the 11 ES refreshed for 3 days at 45 degrees shows that the Carbon can be barely seen when the refreshing time is 15 minutes, which is a severe condition for the fog density on the other side. This measurement suggest that the refreshing condition should be more moderate, but a test is mandatory in order to select the optimal condition for fog and sensitivity at the same time, given the aim of identifying particles from beryllium to carbon. Given the non availability of other emulsions exposed to Carbon, it was decided to expose a few emulsion sheets (third sample) during the exposure at Chiba and use them to perform a test at 42 grees with 2 and 3 days of refreshing soon after the exposure

October 12th, assembling of the 2 chambers to be exposed and of additional 14 emulsions to be used for test.

October 13th, exposure at Chiba from 10 pm till 1 am of the 14th.

October 14th, unpacking of the 2 chambers and 14 additional emulsions. 8 of these emulsions are used for the refreshing test at 42 degrees for 2 and 3 days, to be developed for 10, 15, 20 and 25 minutes. All emulsion sheets are labeled and fiducial marks were printed on 66 emulsions of R0 type. The refreshing for 8 test emulsions sheets started at 11:38 p.m.

October 15th, fiducial marks we printed on the remaining emulsions: 17 R1, 34 R2 and 22 R3. The solutions for the development are prepared in the early afternoon and the development is started at 10:15 pm for the 66 R0 emulsions in 2 batches of 33 ES each (one for each exposed chamber).

October 16th, the development of 66 R0 ES finished at 2:00 a.m. and the glycerin bath was prepared soon after. The 2 batches of developed ES were put to dry at 3:40 a.m. after the glycerin bath. In the evening, at 11:50 p.m. the refreshing was interrupted by the rump down which took one hour to achieve 20 degrees Celsius and 50% R.H.

October 17th, at 3:00 a.m. 4 ES were taken out from the refreshing chamber and packed. At 3:14 a.m. the rump up was given to raise the temperature again to 42 degrees and the relative humidity to 98%.

October 18th, at 3:45 a.m. the rump down was given to lower the temperature to 20 degrees and relative humidity 50%. The emulsions were taken out in the afternoon, around 3:00 p.m. The refreshing of 34 ES from the R2 sample was started at 3:48 p.m. with the rump up. In table 5 it is reported the labeling of the 8 test ES used to optimize the refreshing and development conditions.

Label	Refreshing time (days)	Developing time (')
T1	2	25
T2	2	20
T3	2	15
T4	2	10
T5	3	25
T6	3	20
T7	3	15
T8	3	10

Tab. 5: labeling of the test emulsions.

October 19th: the measurement with the automatic microscope (UTS) shows the PH volume distributions as reported in Figs. 9 to 12.

Fig. 9: PH volume for 2 days refreshing and 15 minute development

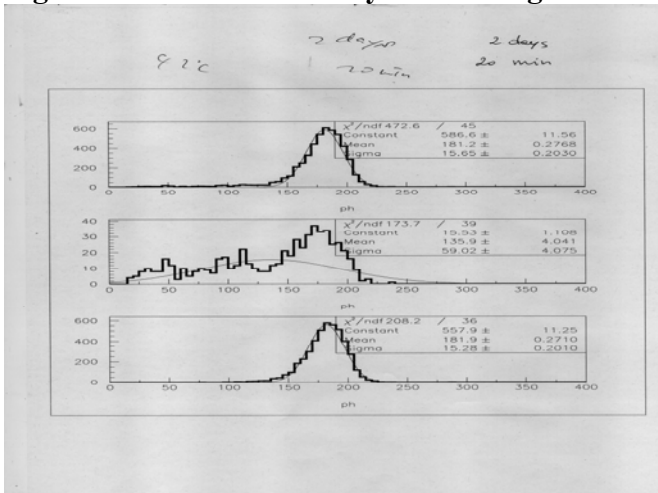


Fig. 10: PH volume for 2 days refreshing and 20 minute development

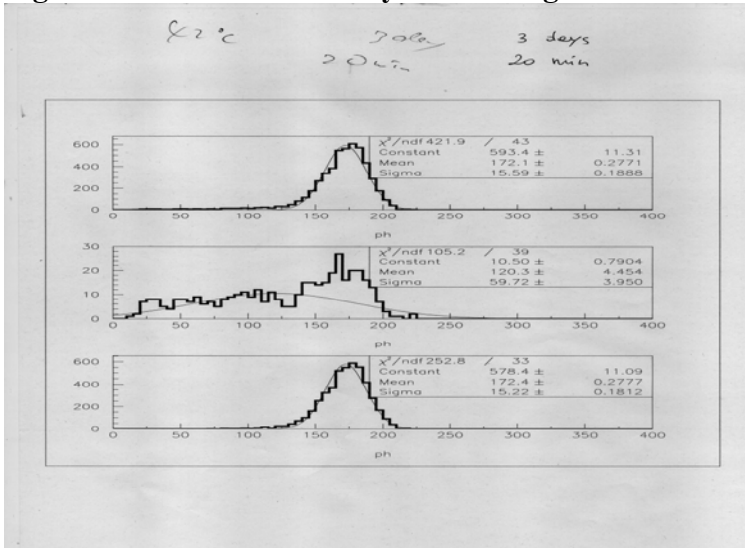


Fig. 11: Ph volume for 3 days refreshing and 20 minute development

In the figures, the top plot shows the overall PH volume distribution, the middle one the PH volume after a 3 sigma angular cut on the beam, the bottom one the PH volume inside the 3 sigma cut. According to these plots, we have selected the conditions of 3 days refreshing and 15 minutes development.

October 21st, refreshing of R2 ES ended at 4:48 p.m. Emulsions taken out from the refreshing chamber at 8:20 p.m. The refreshing of R3 type started at 8:44 p.m.

October 22nd, 66 ES were completely dried and packed in the envelope. The development of 34 films (R2 type) was performed at 11:00 pm.

October 23rd, the drying of 34 R2 ES started at 1:10 am.

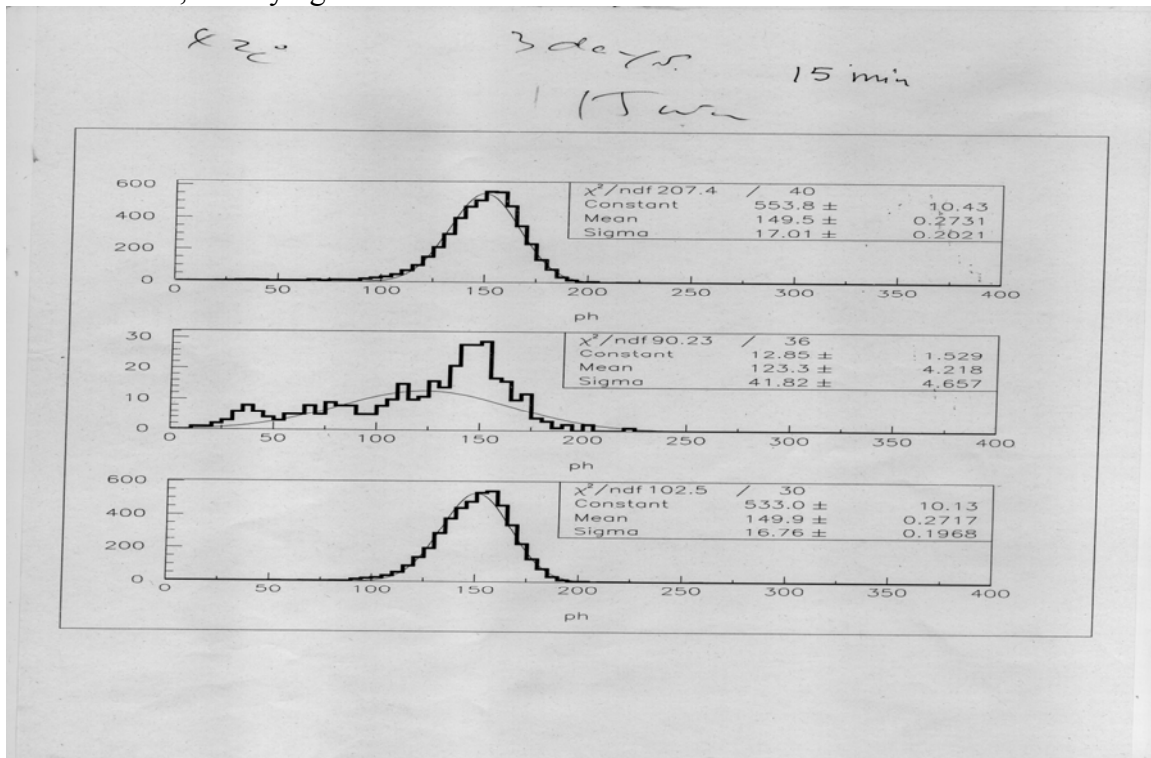


Fig. 12: Ph volume for 3 days refreshing and 15 minute development.

October 24th, the 17 emulsions (R1 type) were brought back from Tono. Their development started at 11 p.m.. The rump down at the refreshing chamber was given at 9:19 p.m. for the 22 emulsions (R3 type).

October 25th, the drying of 17 R1 ES started at 1:00 a.m. while the drying of the 22 R3 started at 4:00 a.m.

October 27th, all emulsions are packed except five: M24, M27, M33, C34, C36 which need additional washing and will be delivered afterwards.