Description of the Project

We propose a measurement of energy spectrum and rate of the secondary particles produced by light ion beams with energy of therapeutically interest (^{4}He at about 150 AMeV and/or ^{16}O at about 400 AMeV) in a Poly-methylmethacrylate (PMMA) target and in a thick water target. These measurements will first study the fragmentation of the beam in the water target and then we will estimate the flux of large angle secondary, namely prompt γ's, charged particles and γ's from positron annihilation (γ-PET), induced by the beam in PMMA. These last fluxes could be of interest to monitor the beam dose release during the treatment

Dose Monitoring setup:

The experimental setup that will study the charge and neutral flux emitted at large angle with respect to the beam, for dose monitoring purpose, has been already been used for similar measurement for ^{12}C beam [1] and is shown in fig.1.

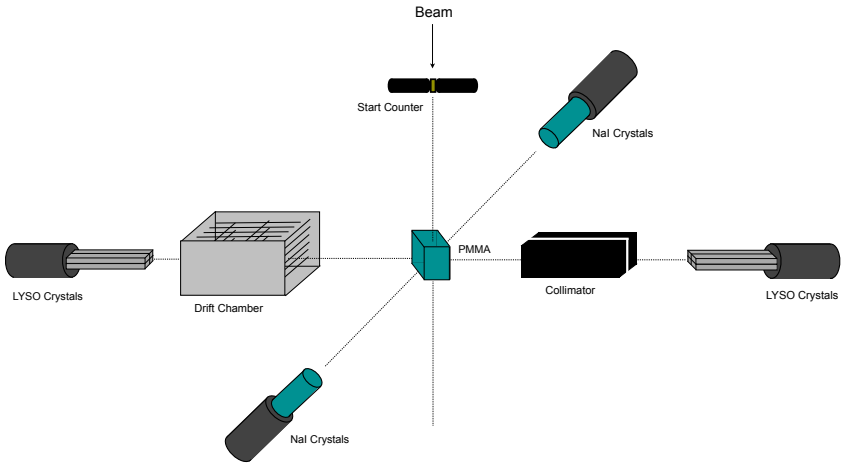

Fig.1 The experimental set up of the flux measurements of charged and neutral secondary particles

A fast plastic scintillator will give the arrival time of the beam before impinging on the PMMA. The LYSO crystal (3 x 3 x 12 cm^3) during the data taking will be placed at different angles (60^0,90^0,120^0) with respect the beam (left part of the figure) to probe the angular dependence of the energy spectrum.

The LYSO detector will be at a distance of 50 cm from the phantom, and will measure the energy and the TOF, both for neutral and charged components. Since we would like to investigate the possibility to reconstruct the Bragg peak position exploiting the information carried by charged particles produced in the PMMA during irradiation, we will tracked the charged secondary trajectories using a drift chamber placed in between the LYSO crystal and the PMMA target. We will also instrument the opposite side with respect to the phantom (right part of the Fig.1) with a identical LYSO crystal, placed behind a lead collimator, to study the emission profile of the prompt γ's. An accurate selection of prompt photons, amongst all neutral secondary components, can be pursued exploiting the excellent time resolution of LYSO detector (σ_t~300ps@3MeV). We also plan to use two NaI crystals (cylinders of h=5 cm and r=5 cm) acquired in coincidence to measure the in beam γ-PET emission. The beam energy should be changed during the data taking to move the Bragg Peak position in few mm steps.

Fragmentation setup:

The second setup is shown in Fig.2, and will provide the yield of fragments of different species produced on 10-15 cm thick water target by ^{4}He at150 AMeV and/or ^{16}O at 400 AMeV. The measurement will be taken in the $0^0 \div 30^0$ angular range, to detect the forward collimated heavier fragments, and will exploit a technique already used to detect ^{12}C beam fragment at GSI [2,3].

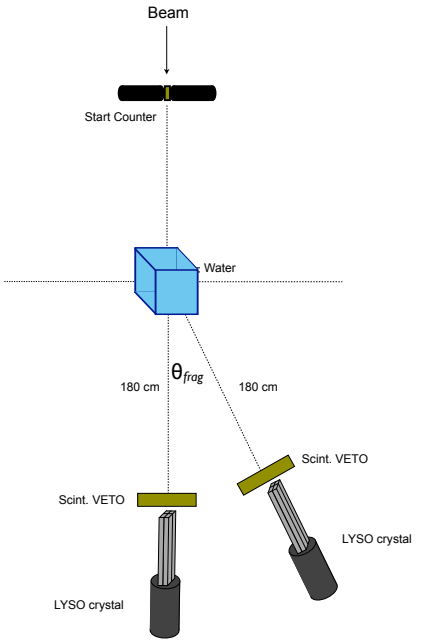

Fig.2 The experimental set up of the beam fragmentation measurements on a water target.

The fragments will be detected the same two LYSO crystals of the previous setup, that will provide the fragment energy and the arrival time. The distance between the LYSO's detectors and the water target will be 180 cm, to have larger path to better exploit the fragment TOF information. The use of two crystals allows performing measurements with different systematic errors. A ΔE detector, made of plastic scintillator, will be placed in front of the LYSO to separate neutral form charged particles. A Drift Chamber, placed in front of one ΔE detector, will track the fragments and will provide the efficiency of the two scintillators on the charged component.
To identify the different population of fragments (protons, deuterium, He, Li, etc.) we need to exploit the distribution of ΔE from plastic scintillator versus the residual energy E measured in LYSO. The performance of the LYSO device are such [1] (σ_E~10%@1MeV) that should allow a powerful particle ID even for light, fast fragment, also taking into account the light yield saturation due to Birk's effect. Furthermore, the high density, large depth (ρl~90g/cm^2) of these detectors will contain most of the produced fragments.
After the identification of the different particles the kinetic energy of the fragments will be derived by the TOF measurements.
The FEE electronic system and the DAQ of both set up are based on NIM+VME system + PC. We would provide all the electronics, cables, rack, DAQ, DAQ pc.

Logistic related with this measurement

1) Possibility to use non-flammable gas bottles in the experimental room (AR/CO_2 mixture for drift chamber). Possibility to have AR and CO2 gas bottles provided by the Center.
2) Possibility to have the really modest flux (about 2 l/h) of gas exhausted in air. If this is not possible we need to have a plastic gas piping out of the experimental room.
3) Possibility to place some electronics nearby the experimental site (within 1-2 meters)
4) To have a physical space around the irradiated phantom of the order of 2 meters to allow us to place the detectors
5) The beam rate should not exceed few MHz
6) We need to pass a 20 meters long optical fiber to connect the DAQ PC-server in the control room with the VME DAQ in the experimental room or, alternatively, ethernet connection inside the experimental Room.
7) We need to know the radioprotection procedure to have access to the Center 30 days in advance the data taking.
8) Availability of lead (or iron) bricks for the shielding of the detectors.
9) Availability of standard radioactive sources (^{60}Co, ^{22}Na, ^{137}Cs).
10) If possible, it would be useful if the Center can provide the Water target.

A key point in the experiment preparation is the mechanics. Since we would like to measure at a sub-millimeter level the Bragg peak position, we should know as soon as possible the layout of the experimental room to build suitable structure to hold and move the detector (see angle scan). If a pre-

existing structure (tables, or other) is available we should know as soon as possible the geometry to match the detector inside this existing structure.

To prepare the experiment we should know also if it would be possible to have cables going from the experimental room to the control room, and how many cables we are possibly allowed to take out. In principle we would need order of 10 cables going out.

It could be useful to have stable environmental condition or to monitor the temperature.

We do not need:

- To take data in a unique solution: we can stop and restart without recalibrate the setup, if the setup is not dismounted.
- To have a monitor of the dose: the beam will be counted by the start counter scintillator read out by multi-hit TDC to give the correct ions number. A comparison with the monitoring system of the Center of course is welcome.
- To have a PMMA phantoms made for us. We can provide them.
- Computing, data storage.

Schedule of the work

Imaging Measurements	**Fragmentation measurements**
1. During the data taking (at HIT): *2 shift of 8 hours* • Calibration of the detectors "on site" • Timing of the detectors "on site"	1. During the data taking (at HIT): *2 shift of 8 hours* • Timing of the detectors "on site"
2. Before the data taking (in home institution): *1.5 months of work* • Implementation of the DAQ system • Implementation of the Trigger system • Calibration of the detectors	2. Before the data taking (in home institution): *1.5 months of work* • Adapt the DAQ system to work in a new configuration with different timing and rates
3. After the data taking (in home institution): *2 months of work* • Analysis of the neutral particles • Analysis of the charged particles • Fluxes and Rates calculations	3. After the data taking (in home institution): *4 months of work* • Analysis of the neutral particles • Analysis of the charged particles • PID with dE/E and TOF • Kinetic energy reconstruction

Total:
4 beam time shifts of 8 hours + 1 days on site before beam time to setup the apparatus
3 months of preparation at home institution (DAQ development and detector optimization)
6 month of data analysis at home institution

Bibliography:

[1] Agodi et al, (2011) JINST 7 P03001 doi : 10.1088/1748 − 0221/7/03/P 03001.
Agodi et al, (2012) PMB/427403/PAP/284627.
[2] E.Haettner, H.Iwase and D.Schardt (doi: 10.1093/rpd/nc1402)
[3] K.Gunzert-Marx, H.Iwase, D.Schardt and R.S.Simon (doi: 10.1088/1367-2630/7/075003)