The role of detectors in nuclear physics measurements for radiotherapy and space applications

Chiara La Tessa
Cancer radiotherapy

- 50% of all cancer patients undergo radiotherapy as part of the treatment
- X-rays are by far the most widely used beam but in the past decades the application of charged particles has gained popularity
Space radiation environment

- GCR ( Galactic Cosmic Rays)
- Solar particle events (mainly protons)
- Trapped particles (protons and electrons)

Low dose and chronic exposure
What ties them together?

**Space**

Combine the composition of the radiation field and dose to biological effects -> Health risk

**Therapy**

Treatment planning verification and optimization, online range verification, extension to other ions and diseases...

Physics and biology experiments to understand basic mechanisms and characterize specific systems

Improve the predictive power and accuracy of deterministic code, Monte Carlo and treatment planning systems
Physical processes of interest

- Energy loss
- Lateral scattering
- Nuclear fragmentation

Space
- Space craft hull and structure
- Shielding
- Astronaut’s body

Radiotherapy
- Elements on the beam line (range shifter, collimator…)
- Patient’s body
SPACE RADIOPROTECTION
Some missing pieces of the puzzle
What codes predict for thick shielding

GCR spectrum interacting with 20 g cm$^{-2}$ Al shielding

d, t, $^3$He, $^4$He

Protons

Boundary condition: Full GCR spectrum
What codes predict for thin shielding

- **400 MeV/nucleon $^{12}\text{C} + \text{Al Cross Sections}**

- **610 MeV/nucleon $^{40}\text{Ar} + \text{C}**

- Effective Charge vs. Cross section (mb)

- Particles per $^{12}\text{C}$ (mass$^{-1}$ MeV$^{-1}$) vs. Energy (MeV/u)

- **Data, 2.5 degree acceptance**
- **PHITS, 2.5 degrees**
- **Data, 7.3 degree acceptance**
- **PHITS, 7.3 degrees**

- Cross section (mb)

- Fragment Charge vs. Cross section (mb)

- Particles per $^{12}\text{C}$ (mass$^{-1}$ MeV$^{-1}$) vs. Energy (MeV/u)

- **$^{4}\text{He}$**
- **$^{3}\text{He}$**
The experiment (performed at NSRL, US)

- **Beams**: H to Fe
- **Energies**: up to 1500 MeV/u
- **Targets**: elemental (C, Al) and composite (PE, H$_2$O)

**Detectors**
- Pixel chamber
- Plastic scintillators
- Liquid scintillators
- NaI crystals
- BaF$_2$ crystals

**Methodologies**
- Energy deposition ($\Delta E$ and $E$)
- Time-of-flight (TOF)
Results

Outputs:
- yield
- kinetic energy of all fragments types (including isotope discrimination) at several angles

Double-differential cross sections
RADIOThERAPY
WITH IONS
Real-time verification of the PTV position during a treatment

**Idea:** Exploit fragmentation of the primary beam at large angles (>60 deg) to monitor the position of the PTV – Planned Target Volume

**Pros compared to PET**
+ Online
+ Better resolution (<1 mm)
+ More affordable

\[ ^{12}C \]
\[ E = 220 \text{ MeV/u} \]

PMMA target

\[ \gamma \]
protons

\[ 5 \text{ cm} \]
\[ 20 \text{ cm} \]
Experimental setup

- **Beam energy:** 220 MeV/u
- **Target:** 5x5x20 cm² PMMA

**Detectors:**
1. CMOS and plastic scintillator (START) for beam monitoring
2. Plastic scintillator (VETO) and crystals (LYSO and BaF) for ∆E-E and TOF measurements
3. Gas chamber and CMOS for particle tracking
2D spatial distribution of secondary protons

Primary beam

Target entrance

Bragg peak depth
RADIOTHERAPY WITH IONS AND SPACE RADIOPROTECTION
TEPC (Tissue Equivalent Proportional Chamber LET-1/2 Far West Technology) is equivalent to a tissue sphere of 2 μm diameter

- Lineal energy spectra
- Dose profile
- Radiation quality factor ($y_D$)
- RBE estimate
It would be very interesting to add a charge-identification detector in front of the TEPC to disentangle the contribution of all particle types to the total spectrum.
Thank you for your attention