Preparation of laser-proton cell irradiation experiments at L2A2

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December 14, 2020

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Target Normal Sheath Acceleration (TNSA)

- Laser energies 0.1 J – 100 J
- Laser pulse duration ns – few hundreds of ps
- Accelerated ions up to 100 MeV/u

Margarone, proc. 3rd ELIMED workshop (2016)

Schreiber, HP Laser Sci. Engin. 2 (2014) e41
Laser Laboratory for Acceleration and Applications (L2A2)

- Located in Santiago de Compostela, Spain
- Operating since 2017
- First proton acceleration in November 2018

- 1.4 J
- 50 TW

(More info in Juan Peña’s talk)
Radiobiological effect

- Significant dose needed for relevant biological effects (0.5–5 Gy)
- If fluence is too low, multiple shots are needed
- DNA double strand breaks (DSB)
- DSB detected via $\gamma$-H2AX immunofluorescence staining

Cell cultures

- Elaborated at IDIS
- Carry to L2A2 in a live transport box
- Biological effects analyzed at IDIS
- Possible comparison with $\gamma$ rays

- Sterilized flask
- Cells grow on 7 $\mu$m polyethylene layer
Setup scheme

- Laser
- Pinhole
- Target
- Vacuum chamber
- Ionization chamber
- Cell culture
- Kapton foil window
- Electrons
- Protons
- X-Rays
- Magnets
Energy separator

- $B_{max} \approx 0.65 \, T$
Kapton window

- Kapton window Ø5 mm
- Must hold $10^{-6}$ mbar

- Foil thickness 7.6 $\mu$m

Sketch provided by Thermal Vacuum Projects, S.L.U.
Focalization system

- Solenoid, quadrupoles
- Focalization strongly depends on kinetic energy
- Expensive and large devices
Fluence-dose relation

- For a given energy,
  \[ D = \frac{1}{\rho} \frac{dE}{dx} \Phi, \]

- Stopping power of protons in water obtained from GATE (GEANT4) simulations

\[ D = \frac{dE}{dx} \left[ \frac{\text{keV}}{\mu\text{m}} \right] \cdot \Phi \left[ \frac{1}{\text{cm}^2} \right] \cdot 1.602 \cdot 10^{-9} \text{ Gy} \]

J. M. Calatayud TFM (2019)
Beam Characterization

Detectors used with two objectives:

- Characterize the beam before cell irradiation: **CR-39, RCF, Ionization chamber**
- Monitor the beam during cell irradiation (shot-to-shot fluctuations): **Ionization chamber, Faraday cup, SciFi detector**

Not possible to detect particles behind the culture due to energy of ions
CR-39 (PADC)

- CR-39 track detector chips
- Some PADC have strong correlation between track size and energy, others do not. Both relevant
- Even tiny tracks (1 µm) strongly overlap at fluences of $10^6$ mm$^2$
Radiochromic films

- **Type EBT3**: 0.1–20 Gy
- **Type HD-V2**: 10–1000 Gy
- No post-exposure treatment
- For beam spatial distribution measurement
- Energy independent (far from Bragg peak)

M. Seimetz et al., IEEE Transactions on Nuclear Science, vol. 62, no. 6, pp. 3216-3224
Ionization Chamber

- Online and offline measurement of fluence
- Very thin electrodes, $3 \times 25 \, \mu m$ polyimide graphite coated
Expected performance

- Broad spectra
- Cutoff Energy $E_m \approx 10$ MeV
- Beam in target normal direction
- Dispersion angle of $\sim \pm10^\circ$

Simulations

Final position of the particles in final x-y plane

Deposited dose in final x-y plane

$L_P = 5$ cm, $L_{\text{total}} = 70$ cm, $r_P = 0.5$ mm, $B = 0.635$ T

- Particle trajectory simulations (COMSOL, Matlab)
Simulations

Energy spectrum

Dose deposited by each energy

\[ \sigma \approx 2\% \]

- \( L_P = 7 \text{ cm}, \ L_{\text{total}} = 70 \text{ cm}, \ r_P = 0.5 \text{ mm}, \ E_C = 5 \text{ MeV} \)
Simulations

<table>
<thead>
<tr>
<th>$L_P$/cm</th>
<th>$r_P$/mm</th>
<th>$B$/T</th>
<th>$E$/MeV</th>
<th>$D_m \pm \Delta D$/Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.5</td>
<td>0.685</td>
<td>4.1-6.3</td>
<td>0.0374 ± 0.0028</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>0.685</td>
<td>4.3-6.0</td>
<td>0.0265 ± 0.0015</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>0.4</td>
<td>3.7-6.8</td>
<td>0.0515 ± 0.0052</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>0.685</td>
<td>3.5-7.5</td>
<td>0.0775 ± 0.0114</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>0.685</td>
<td>3.8-6.7</td>
<td>0.0552 ± 0.0059</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>0.4</td>
<td>3.1-8.9</td>
<td>0.1041 ± 0.0192</td>
</tr>
</tbody>
</table>

- Bigger pinhole implies bigger dose, also higher $\Delta D$
- Similar effect lowering $B$
Conclusions

- Total distance of particle flight must be minimized
- 10–30 shots needed for 1 Gy dose
- Must achieve $\Delta D_{\text{total}} < 0.5$ Gy

Next steps:
- Resume proton acceleration experiments
- Detector testing, dosimetry (online and offline)
- 2021: First experiments on irradiating living cells
Acknowledgements

Supported by:

- Xunta de Galicia grant GRC ED431C 2017/54
- Generalitat Valenciana, program Grupos de Investigación Consolidables (AICO/2020/207)
- Co-financed by the European Union’s Programa Operativo del Fondo Europeo de Desarrollo Regional (FEDER) of the Comunitat Valenciana 2014-2020 (IDIFEDER/2018/022)

Thank you for your attention!