Delivering Laser-Driven Proton beams to Biological Samples at BELLA iP2

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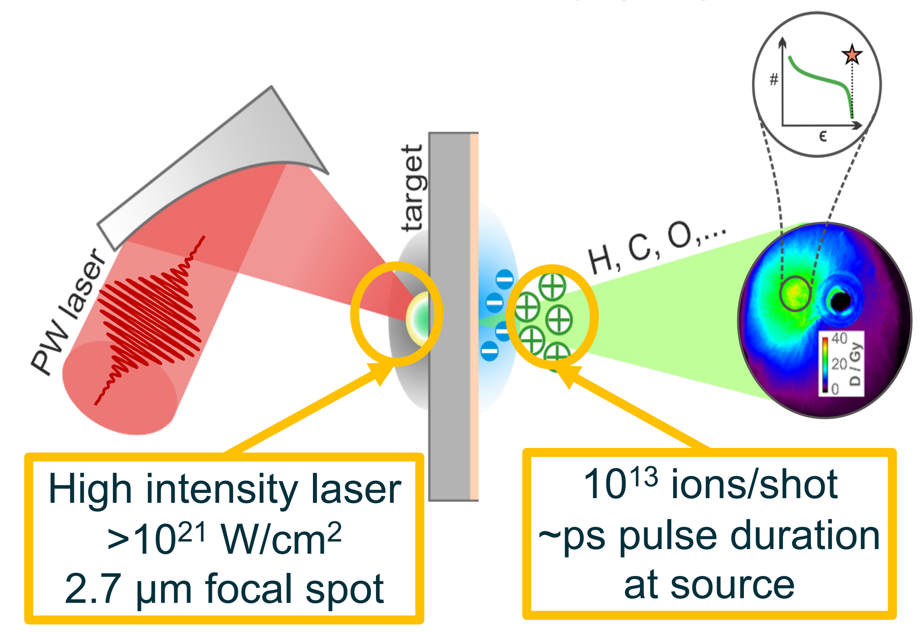
Investigating FLASH radiotherapy (RT) with laser-driven ion acceleration

Laser-driven ion acceleration [1] has been used to explore ultra-high dose rate radiotherapy at the **BELLA petawatt laser facility (iP2)** [2].



Schematic of Target Normal Sheath Acceleration [1]

FLASH RT: **ultra-high dose rate** radiation has been shown to **differentially spare healthy tissue** without compromising tumor treatment [3, 4].

Laser-driven ion accelerators are well suited to study this phenomenon due to their **high intensity**.

The **broadband energy spectrum** could allow for a **uniform *3D* dose profile** if the transport is properly designed [5].

Challenges: beam transport and dosimetry

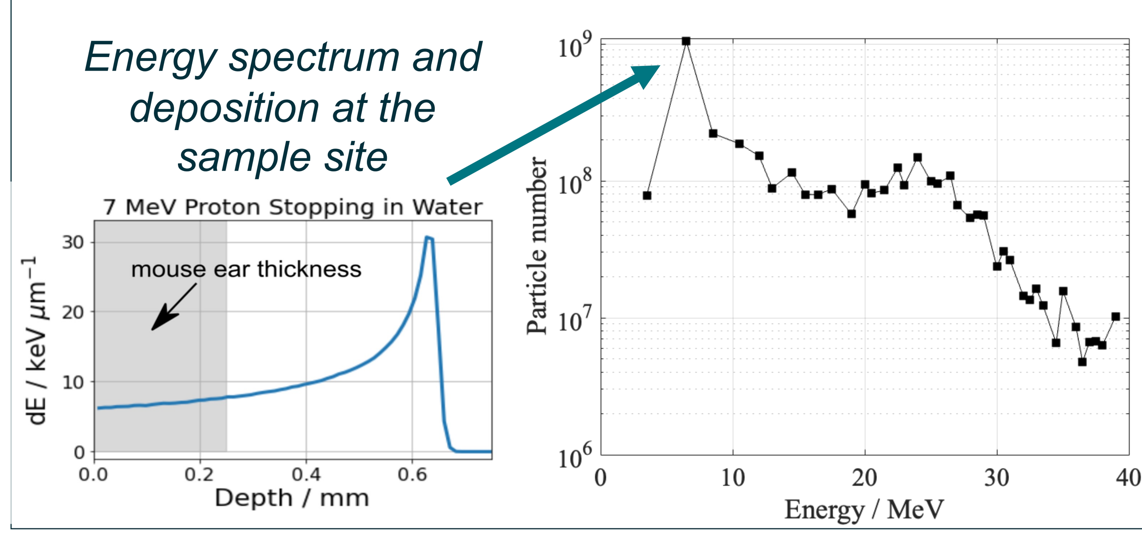
A **beam transport system** is required to:

- collimate the highly **divergent** beam,
- select the desired energy,
- and deliver a **high dose rate** with a **uniform profile**.

Dosimetry is required to:

- account for shot-to-shot fluctuations
- and ensure a uniform dose deposition

Energy spectrum and deposition at the sample site



Permanent magnet-based beam transports for 10 & 30 MeV protons designed and implemented in the BELLA iP2 with dosimetry

A set of compact, **permanent magnet quadrupoles (PMQs)** were used for beam transport, with configurations for collimating **10 MeV** and **30 MeV** proton beams.

After collimation, the beam is deflected for **energy selection** and **separation** from co-propagating **neutrals and electrons.**

Magnet parameters	M1	M2	M3	M4
Inner radius (mm)	5	15	20	25
Gradient B' (T/m)	219.5	59.7	37.3	29.0
Effective length L_{eff} (mm)	50.25	50.10	57.9	60.1
Strength $B' \cdot L_{eff}$ (T)	11.03	2.99	2.40	1.92

PI: Antoine Snijders

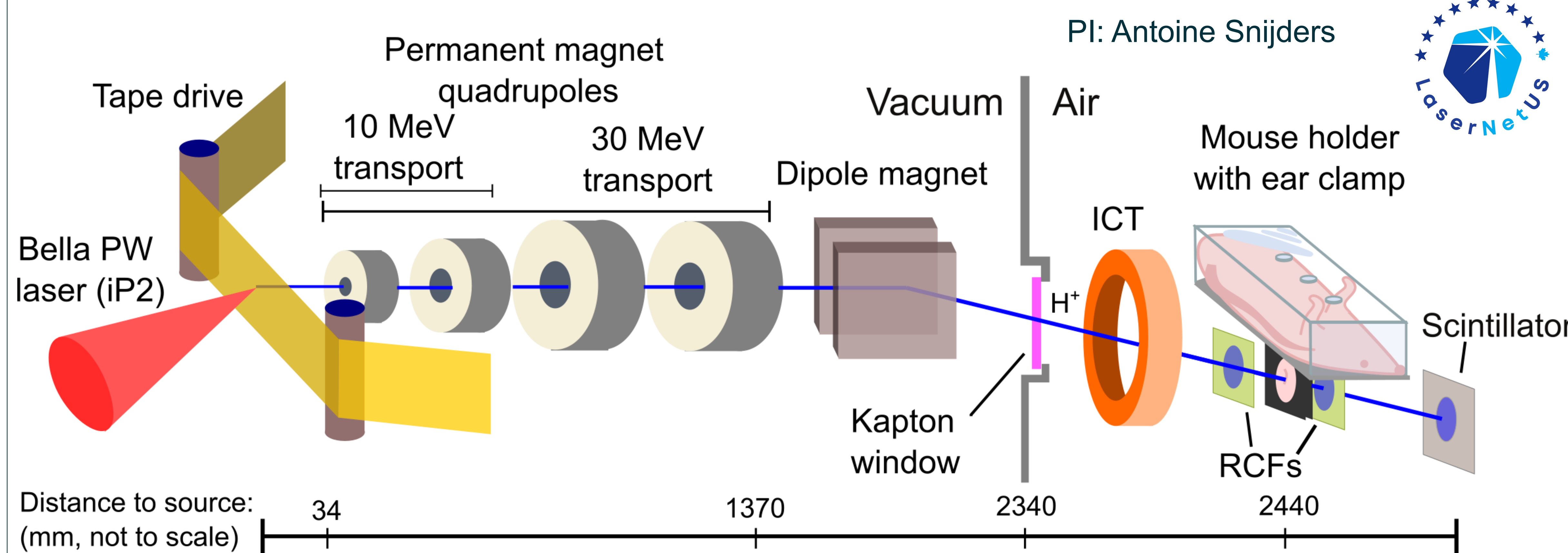
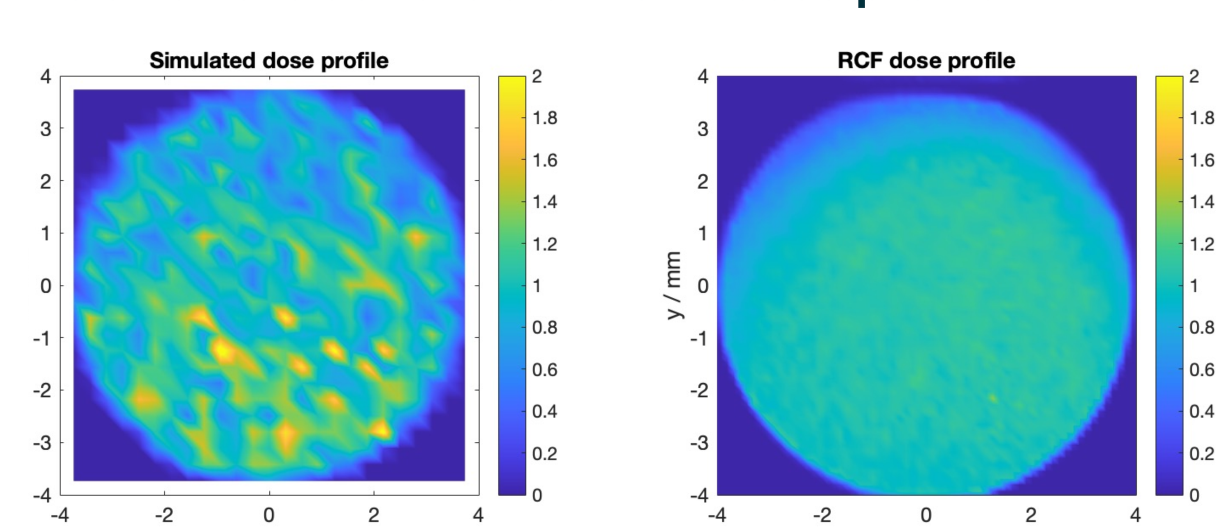


Illustration of experimental setup for mouse ear irradiations. The quadrupole magnets are mounted to motorized stages to easily switch between configurations.

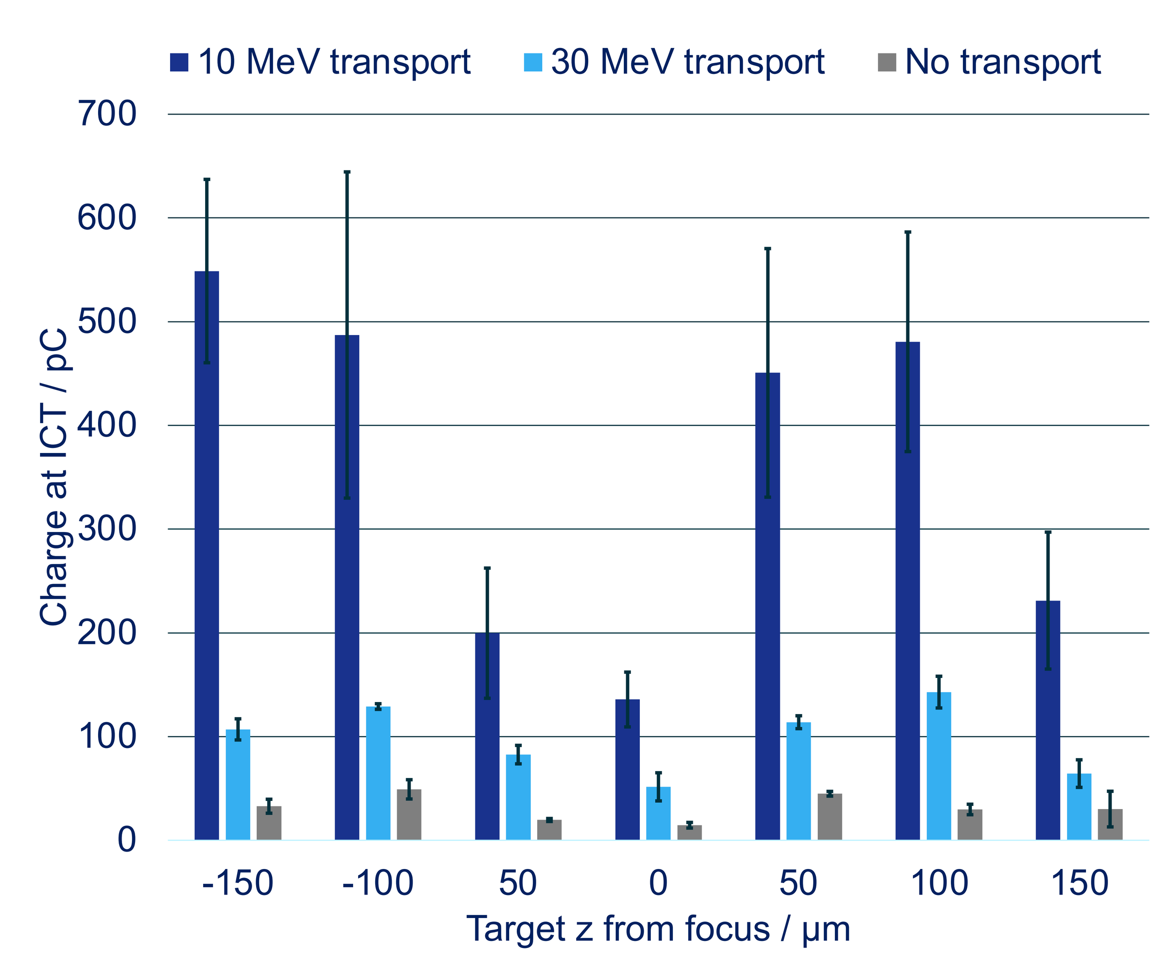
Beam transport system successfully delivered over 1 Gy/shot to the sample while maintaining a uniform dose profile

The wide bore and strength of the PMQs allowed a **large amount of charge** to be collected, boosting the overall dose rate achievable at iP2 **by a factor of 5**.

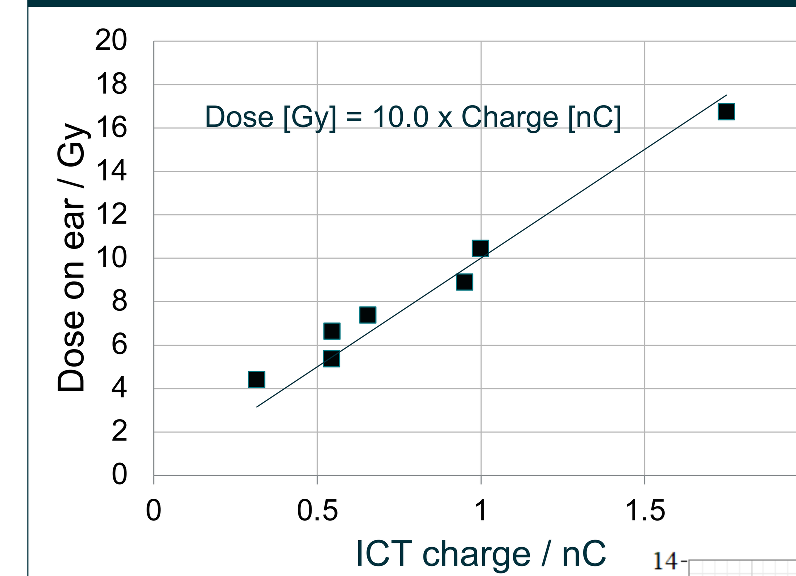
Simulations ensured the correct placement of the transport elements to achieve a **uniform dose profile**.

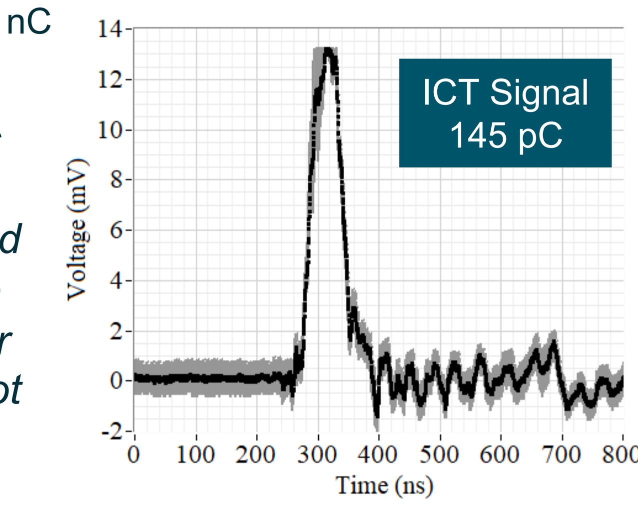


Comparison of simulated (left) and measured (right) dose profiles at the sample location, normalized to mean dose.



Online dosimetry performed with an integrating current transformer (ICT)





The ICT signal (right) was correlated to the dose measured by RCF (top) and now used to estimate the dose delivered on shot, to better account for any shot-to-shot fluctuation.

The dose measured by an *in situ* (*) RCF, D_B, was correlated to the charge measured by the ICT, establishing a **charge-to-dose conversion**, for online dosimetry [6].

Dosimetry with radiochromic film (RCFs)

Modeling the measured beam spectrum through the beamline, the dose values measured by the RCFs were scaled to account for their **LET-dependent response** [7].

$$\eta = 1 - 0.4\exp\left(-4e^{-0.2\, dE/dx}\right)$$

The doses measured by the RCFs placed in front D_A and behind D_C each sample during irradiation were scaled and averaged to determine the **actual dose delivered D_S**:

$$D_S = \frac{1}{2}\left(D_A \frac{D_B{}^*}{D_A{}^*} + D_C \frac{D_B{}^*}{D_C{}^*}\right)$$

References

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This work was supported by U.S. DOE-OS, FES, and HEP under DE-AC02-05CH11231, and by LaserNetUS. J. D. was supported by DOE-OS, HEP under DE-SC0018362 and MSU. S. H. was supported by the DOE-FES Postdoctoral Research Program, administered by ORISE DE-SC0014664. B. Stassel was supported by the U.S. DOE-OS, WDTS, SCGSR program, also administered by ORISE.

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