First simulations of minibeam nozzle with LhARA beam parameters

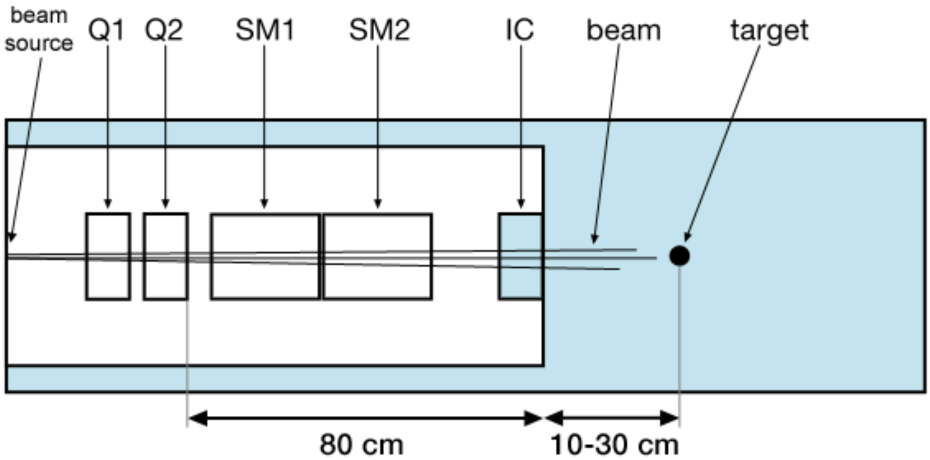
Tim Schneider

Purpose

- Optimise generation of clinical proton minibeams through magnetic focussing
- Minibeams: lateral beam size (FWHM) ≤ 1 mm or equivalently σ ≤ 0.42 mm
- Adequate beam source required (low emittance) for magnetic focussing

Method

- Monte Carlo simulations with TOPAS
- Simulation of new nozzle design as presented in Schneider et al., *Scientific Reports* 10.1 (2020)
- Considered air gaps 10 and 30 cm
- Schematic of nozzle below



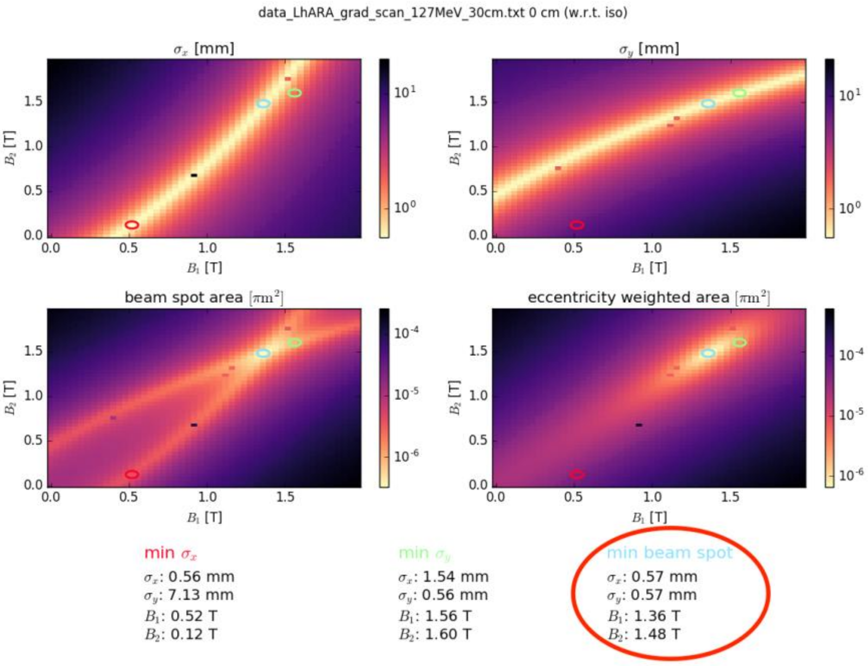
Abbreviations: Q – quadrupole, SM – scanning dipole magnet, IC – ionisation chamber

- Variation of magnetic field in quadrupole magnets Q1 and Q2
- Measurement of beam size at target position as function of quadrupole fields
- Beam source parametrisation:
    - particles: protons
    - energy: 127 MeV
    - energy spread: 0.2 % (σ of Gaussian)
    - beam size (x/y): 2.5 mm (σ of Gaussian)
    - divergence (x'/y'): 0.545 mrad (σ of Gaussian)
    - $r_{xx'}/r_{yy'}$: 1.0

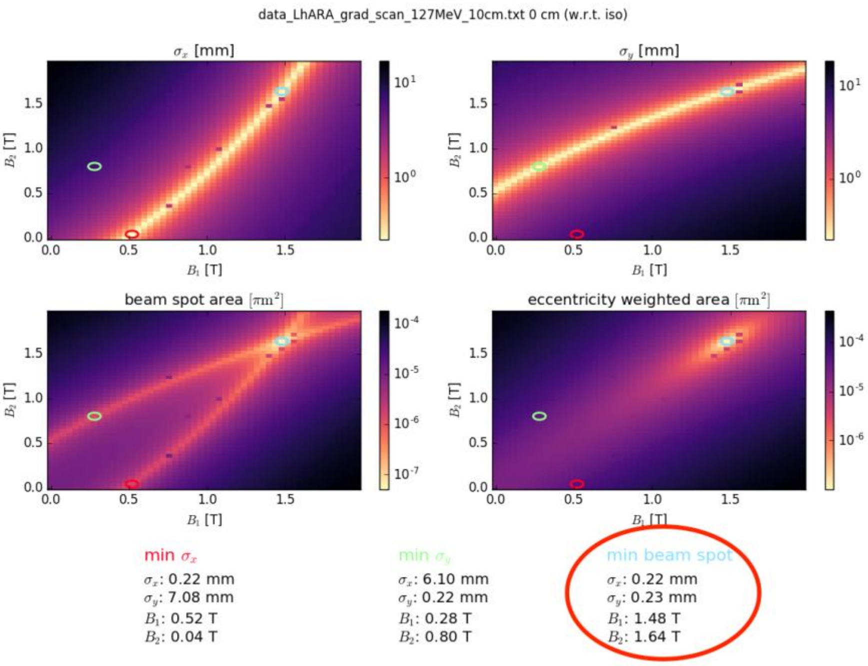
      (r is the correlation factor between beam size and divergence)

Results

Air gap = 30 cm:



Air gap = 10 cm:



Conclusion

- The minimum beam size with conventional proton beams (PBS) is σ = 2 – 10 mm / FWHM = 4.7 – 23.5 mm
- “min beam spot” yield symmetric focussing in x and y, to be preferred
- For air gap of 30 cm min beam size: σ = 0.57 mm / FWHM = 1.34 mm
    - No strict minibeams but very small and big improvement compared to conventional PBS
    - Very likely still useful for minibeam therapy
- **For air gap of 10 cm min beam size: σ = 0.22 mm / FWHM = 0.52 mm**
    - **Clearly in minibeam regime**

Our first simulations indicate that the beam provided by the LhARA accelerator in conjunction with our new nozzle design could be used for proton minibeam radiation therapy.

Next simulations

From here, it would be interesting to simulate beams for a range of other relevant energies, e.g. 50, 80 and 100 MeV.
The data required to perform these simulations would be again:

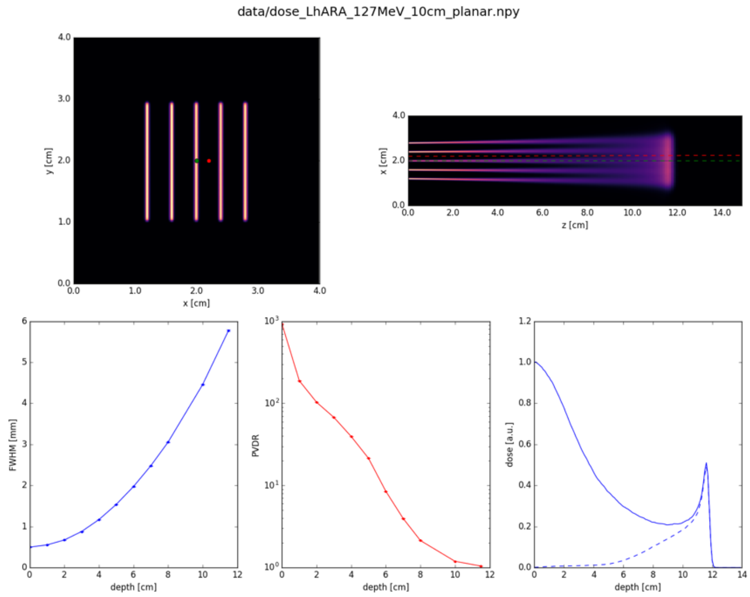
- Energy spread
- Beam size (sigma)
- Beam divergence (sigma)
- Emittance or correlation factor between size and divergence

The parameters are required for each beam energy. Alternatively, a phase space file containing the phase space information (position and angle w.r.t beam axis) for a cross-section of the beam could be used.

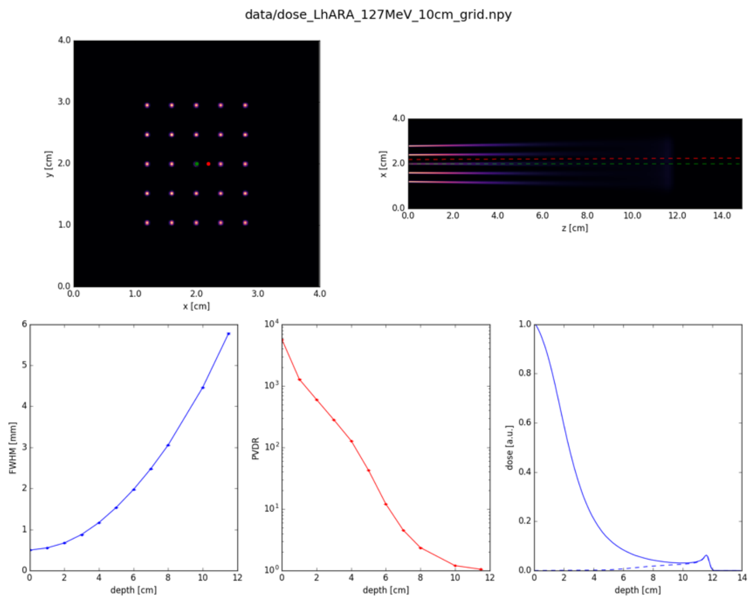
Dose simulations for LhARA beam source

Air gap 10 cm

Array with (scanned) planar minibeams

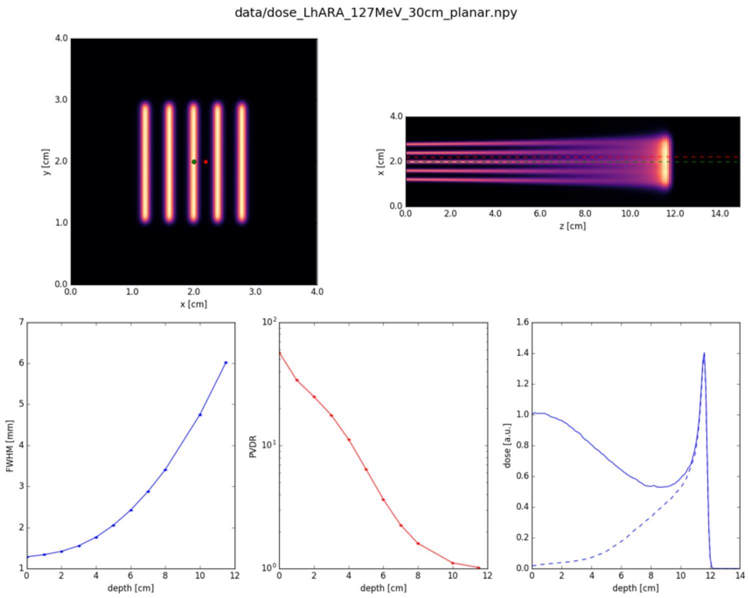


Grid with pencil-shaped minibeams

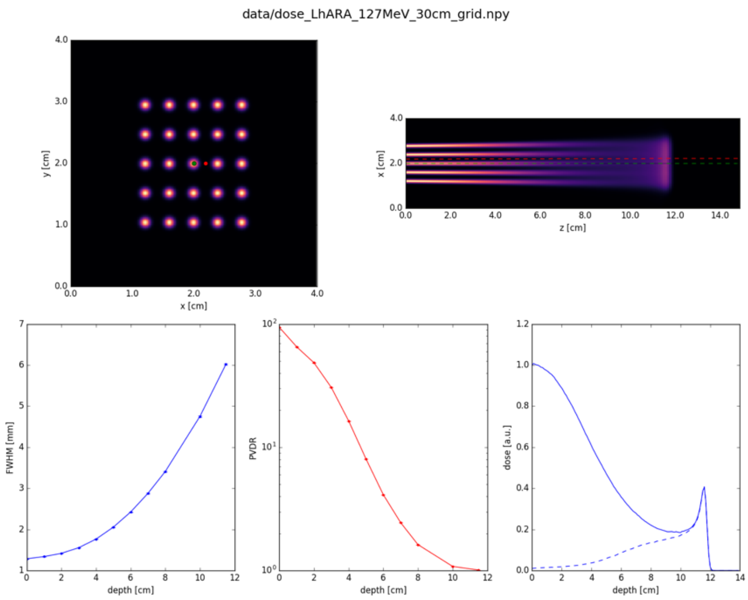


<u>Air gap 30 cm</u>

Array with (scanned) planar minibeams



Grid with pencil-shaped minibeams



Cover from Y. Prezado:

The report is very brief. It is just to share the first results with you and to inquire whether the team could provide us with more data on some other energies in the next weeks (as explained in previous mails), so that Tim could perform a more complete evaluation before ending his PhD work. Tim will write a proper report in the weeks to come.

His results are very promising:

1. The peak-to-valley dose ratios (very important parameter in spatially fractionated RT) can be very high in the first centimetres (good to spare normal tissue), while we could get a homogenous dose coverage in the target. The PVDR in normal tissues are much higher that we can get at clinical centers today, so an even better tissue sparing is to be expected.
2. It looks possible to obtain beam widths of around 1 mm without any mechanical collimator and the beam evolves quite smoothly

In summary: LhARA promises excellent beam characteristics for proton MBRT.

____

Yolanda Prezado, PhD, HDR