Rexolite beam pipe design for proof of concept proton dielectric wall accelerator

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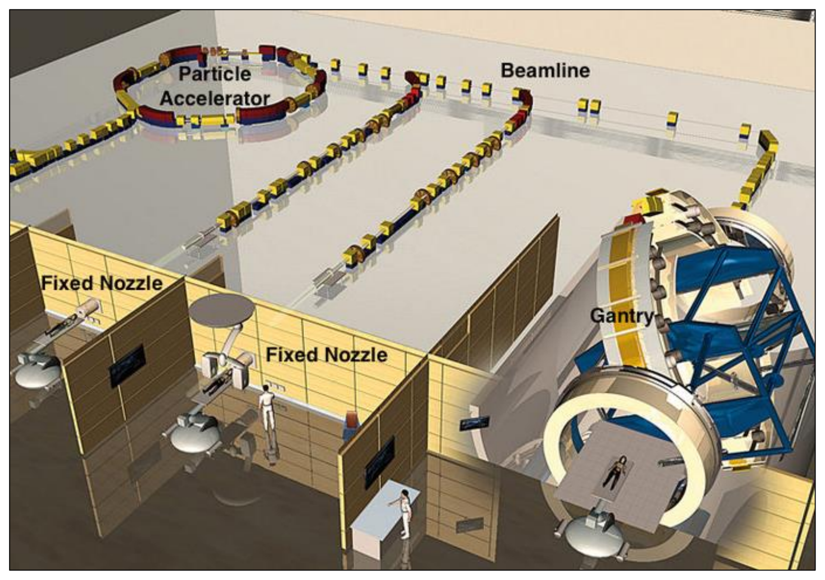
Limited accessibility of conventional accelerators impose constraints on treatment
→ only *2%* of patients who would benefit from proton therapy *actually* receive it [1].

Introduction

Conventional proton accelerator.



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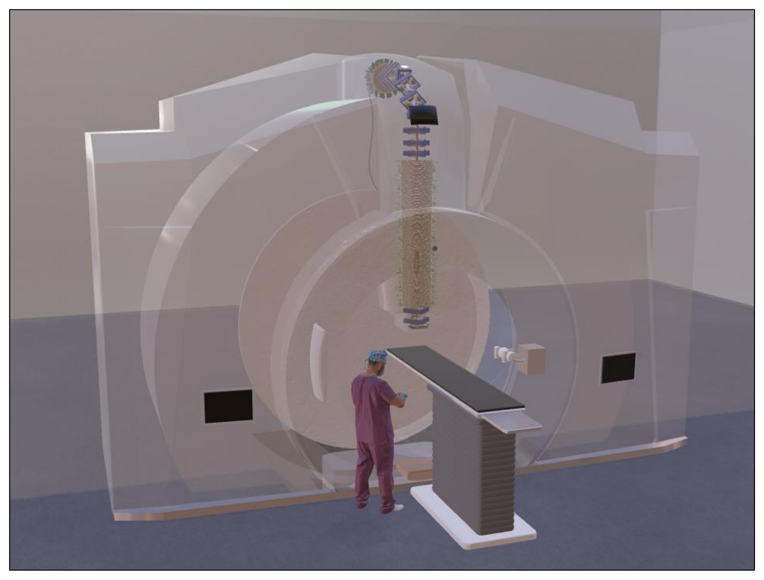
Dielectric wall accelerator



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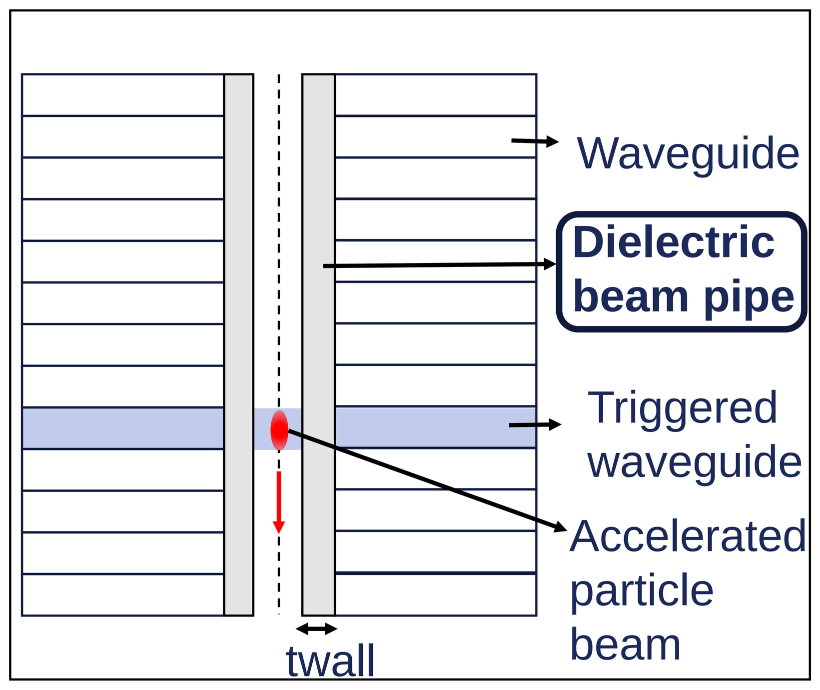
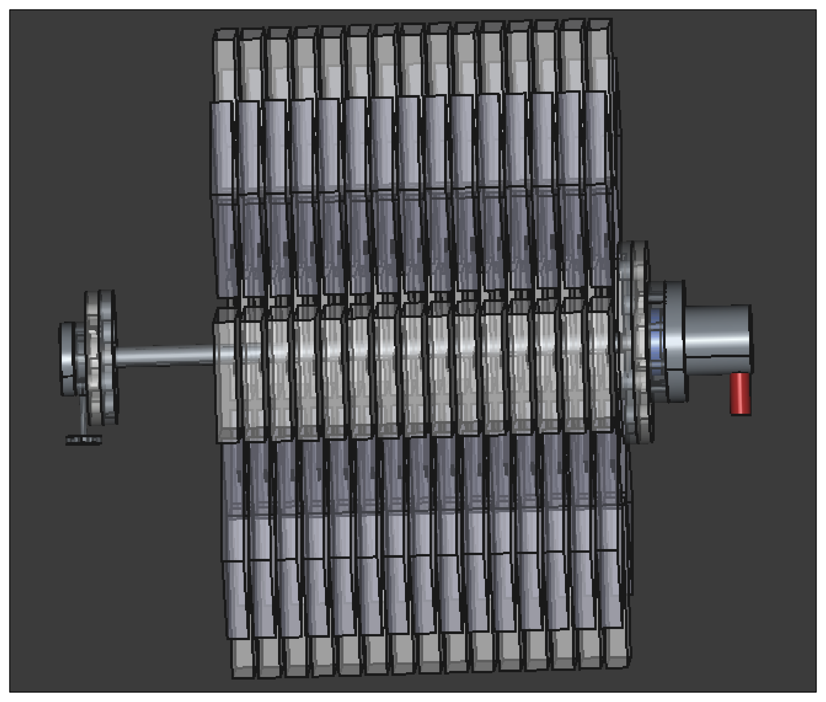
→ Increased accessibility

DWA working principle:



Proof of concept DWA (keV energies):



Objectives

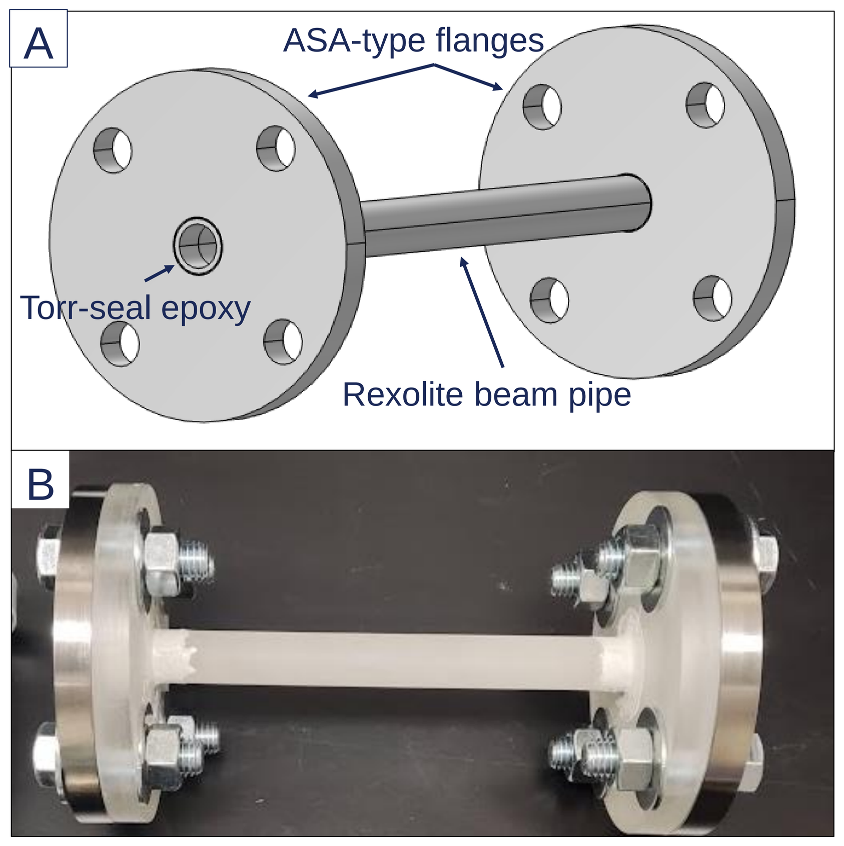
Design and simulate Rexolite beam pipe that:

- ✓ Maintains vacuum of ≤ 10^{-6} Pa within the beam pipe
  - deformation ≤ 0.5 mm;
  - Von Mises stress ≤ $4 \cdot 10^{6}$ N/m²
- ✓ Prevents surface flashover for electrical fields ≤ 10 keV/mm
  - Surface E-field (E_{sf}) ≤ 36 MV/m (for 7 mm sample)
- ✓ Maximizes Accelerating field (E_{acc}) @ beam pipe center

Methods

COMSOL 6.3 simulation studies:

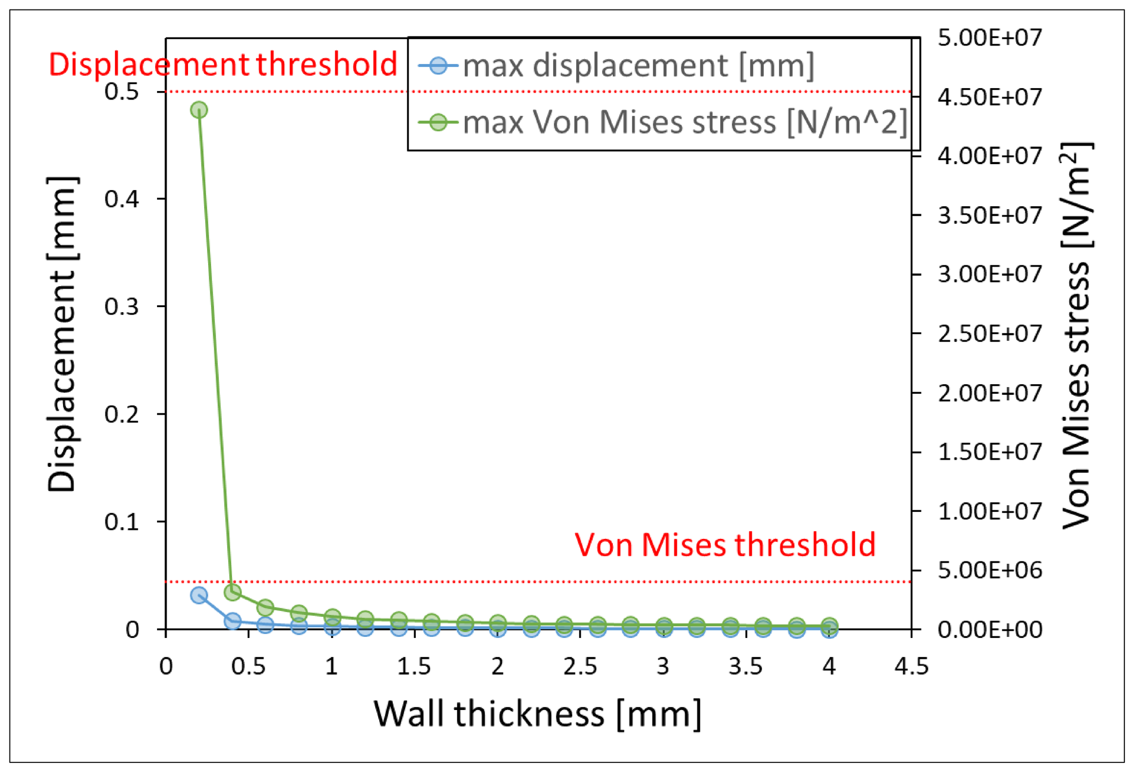
- **Linear buckling**
  - Define 5 most sensitive deformation modes
  - Simulate manufacturing impurities
- **Stationary solid mechanics**
  - Assess maximal displacement + Von Mises stress
  - Wall thickness range: 0.2 – 4.0 mm
- **Time dependent electrostatics**
  - Assess maximal E-fields at surface (E_{sf}) and in center (E_{acc})
  - Trapezoid pulse :1.2 ns rise time; 2 ns flat top; 1.2 ns fall time
  - Peak pulse = 25 kV



Modular design (A render; B physical prototype)

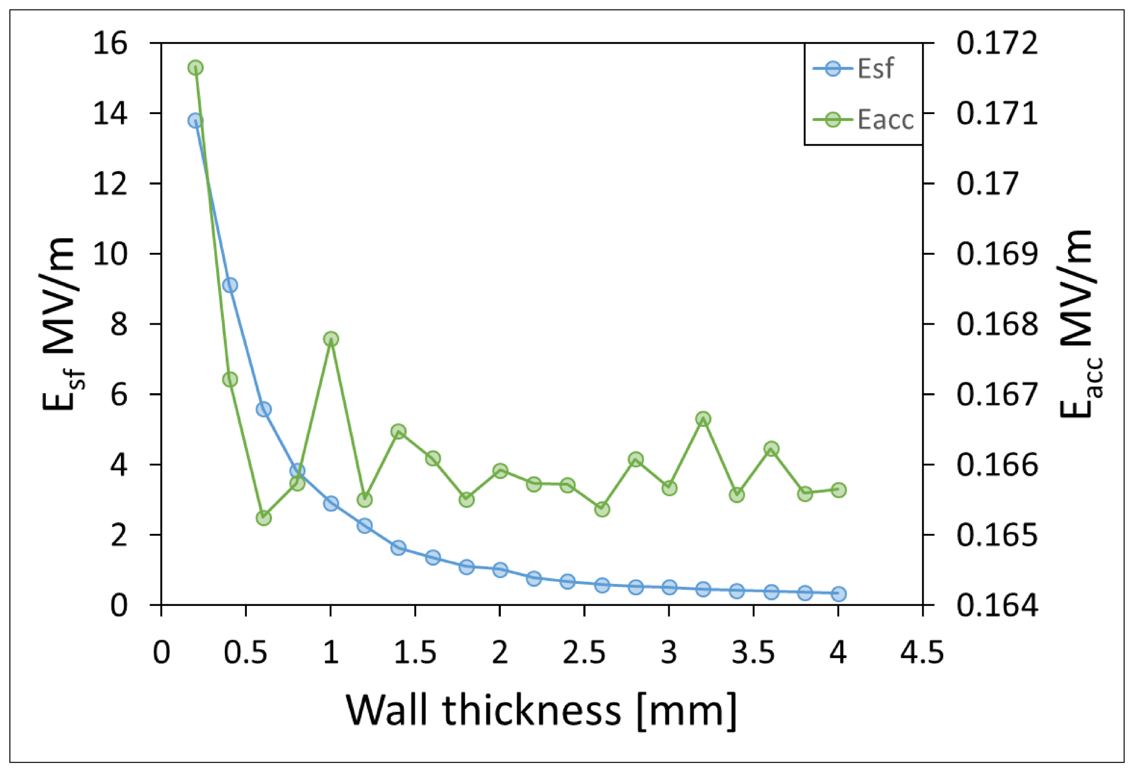
Results

Beam pipe displacement and Von Mises stress dependence as a function of beam pipe wall thickness (twall):



→ Optimal beam pipe thickness = 2.5 mm (asymptotic behavior + rigidity)

Electric field at beam pipe-vacuum interface (E_{sf}) and center (E_{acc}) as a function of beam pipe wall thickness (twall):



- E_{sf} < 36 MV/m → safety factor = 50
- E_{acc} = 0.166 MV/m @ 2.5 mm t_{wall}

Outlook

- Modular design of a Rexolite beam pipe
- Optimal wall thickness determined (2.5 mm)
- Experiments ongoing

Max Displacement	Max Von Mises Stress	E_{sf}	E_{acc}
$1.1 \cdot 10^{-3}$ mm	$0.45 \cdot 10^{6}$ N/m²	0.73 MV/m	0.166 MV/m

Parameters at optimal wall thickness

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[1] Yan, S. et al. "Global democratisation of proton radiotherapy." The Lancet Oncology 24.6 (2023): e245-e254.